

Wakkanai, Japan
June 16, 1971

Dear Dr. Howard:

Thank you for your letter and comments concerning the fossil bed from Tatsunokuchi Tm. It was much appreciated.

Re: the quotation of the vertebrate bearing beds on Cedros.

I'd modify the statement to read:
--- that the ~~strata~~^{sands} vertebrate-bearing ~~strata~~ may be early to middle Pliocene in age. Although these beds are so far not known to contain invertebrates, he notes that they rest on ^{diatomaceous} ~~strata~~ of probable upper middle Miocene (Luisian) and underlie ^{coarsely clastic} ~~strata~~ invertebrate-bearing ~~strata~~ beds of probable mid-Pliocene age.

I hope the delay in getting this to you has not been too great a inconvenience, ~~to you~~. I have been traveling a great deal in Japan.

Frank H. Kilmer

PAR AVION

航空郵便



AÉROGRAMME

Dr. Hildegarde Howard
3045 - O Via Mangrove East
Laguna Hills, Calif
92653

はじめに ここをおる

つぎに ここをおる

Second fold here

差出人郵便番号住所氏名

Sender's name, address and postal code

Kilmer
Sundai American School
4-11, 2-Chome, Tori-cho
Sundai 980, Japan

First fold here

この郵便物には なにも入れたりはりつけたりすることができません

Nothing may be contained in or attached to this

To open cut here

Stratigraphy of the lower part of the Almejas Formation exposed on the north wall of Valle Blanca about 2 miles south of the cannery village, Cedros Island. The measured section ^{follows} the divide between Arroyos Delphin (E) and Tiberon (W.), fossil localities in Arroyo Espectos projected on this section by westward tracing of units. Geology by F. Kilmner 1964, R. Tedford 1965.

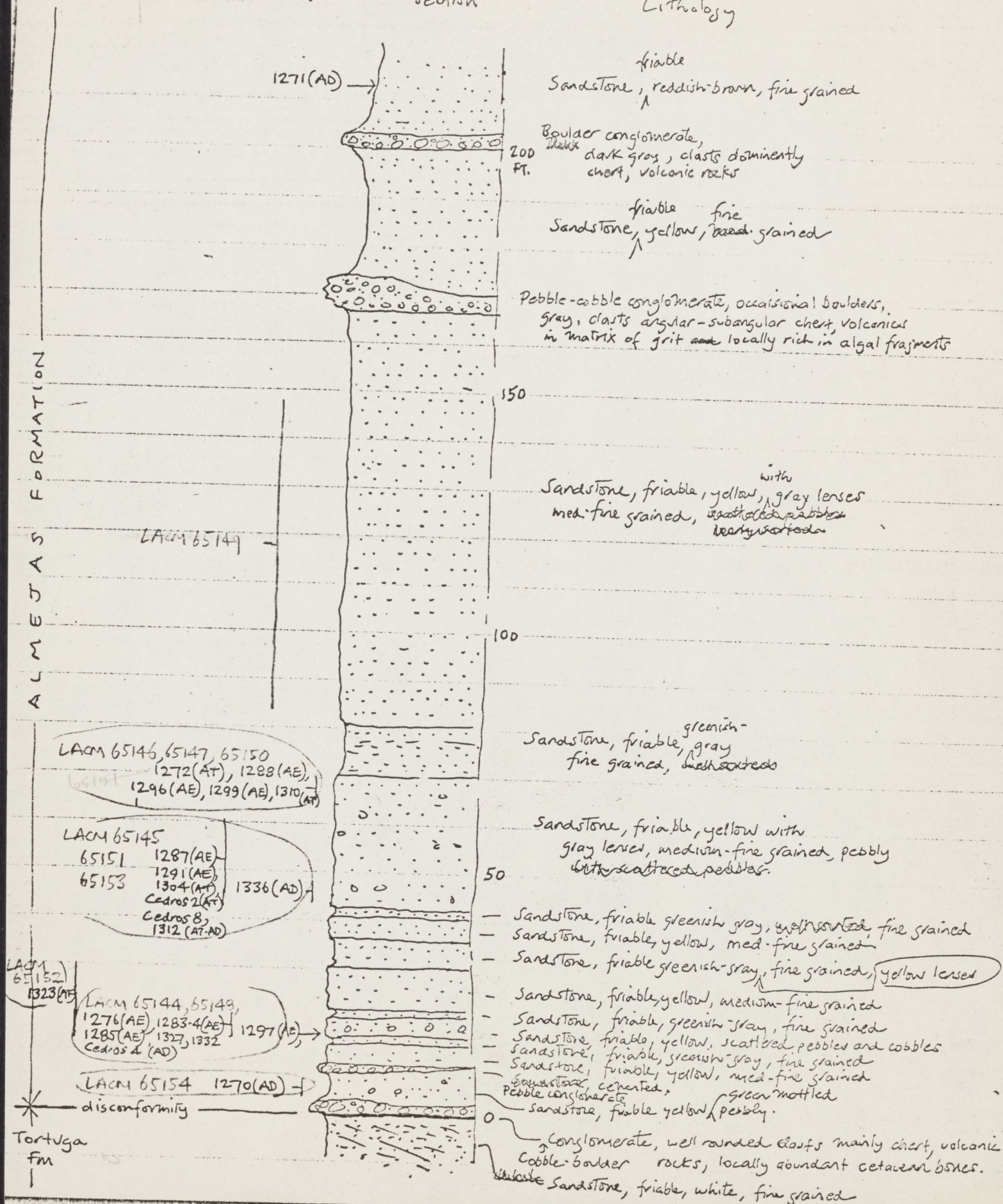
Formation

Fossil Vertebrate Sites

Measured section

Lithology

ALMEJAS FORMATION



2045-Q Via Mariposa East
Laguna Hills, Calif. 92653
October 30, 1970.

Dr. Richard Tedford
Department of Vertebrate Paleontology
American Museum of Natural History
Central Park West at 79th Street
New York, New York 10024

Dear Dick:

Thank you very Much for the revised stratigraphic column for Cedros Island. There are a few numbers not represented, however, and some of these are type localities for new species, it would be helpful to have them spotted.

Here is the list of our locality numbers with notations as to which of yours and Whistler's are included. In parentheses I have indicated the number of feet above the Miocene/Pliocene contact as now indicated on your new column (approx.) or the old notation (where the new column doesn't show the locality). Those underlined are on your new column, those starred are not.

LACM 65144 -- Arroyo Esqueletos (15+ft.)
RHT 1276, 1283, 1284, *1285, 1297

LACM 65145 -- Arroyo Esqueletos (42-60ft.)
RHT 1287, *1291

LACM 65146 -- Arroyo Esqueletos (65+ ft.)
RHT 1288, 1299

LACM 65147 -- E. branch Arroyo Esqueletos (65+ ft)
RHT 1296

LACM 65148 -- Arroyo Delphin ("Unit F")
RHT *1327, *1332; Whistler *"Cedros 4"

LACM 65149 -- Head of Arroyo Delphin ("Unit M")
Jefferson "Cedros 7"

LACM 65150 -- Arroyo Tiberon (65+ft)
RHT 1310

LACM 65151 -- Arroyo Tiberon ("Unit L") (65+ft)
RHT 1272, *1304; Whistler *"Cedros 2"

*1304 in new column
placed with 1291 & 1287*

LACM 65153 -- Ridge between Arroyo Tiberon and Arroyo Delphin
RHT *1312; Whistler *Cedros 8" ("Unit L")

LACM 65154 -- Ridge between Arroyo Delphin and Arroyo Tiberon
RHT 1270 (5+ft.)

LACM 65152 -- Arroyo Tiberon ("equiv. Units 6-8 AE column")
RHT *1323

*1272
placed higher
with 1288, 1294
1299 & 1310*

Tedford - 2

You have two numbers on the column that we do not have LACM locality numbers for: RHT 1336 and RHT 1271. The first one is on the jacketed specimen that seems too fragile to save, hence hasn't been numbered. RHT 1271 I don't find at all. What do you have noted from there?

I'm hoping to get this Cedros paper in shape for the issue of the Condor that is to be a memorial to Padre Miller. The editor tells me such an issue is planned for some time in 1971. It will be particularly fitting to choose the Cedros findings for this issue because of your involvement. After all you, too, are one of "Padre's" "children". Would you have gone into paleo had it not been for him?

Sincerely,

Hildegarde Howard

Stratigraphy of the lower part of The Almejas Formation exposed on the north wall of Valle Blanca about 2 miles south of the cannery village, Cedros Island. The measured section ^{follows} the divide between Arroyos Delphin (E.) and Tibson (W.), fossil localities in Arroyo Esqueletos projected on this section by westward tracing of units. Geology by F. Kilmer 1964, R. Tedford 1965.

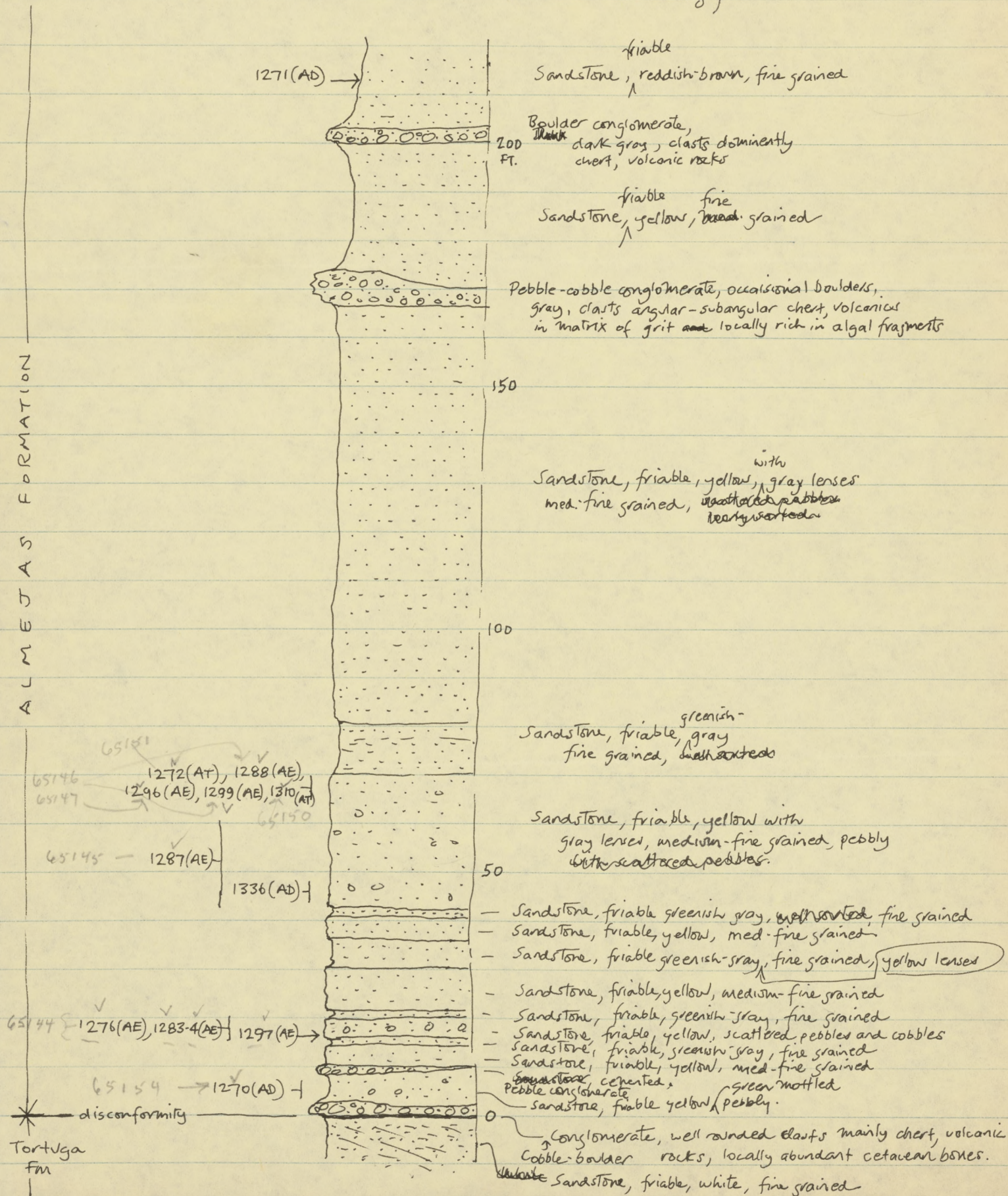
Formation

Fossil Vertebrate
sites

measured
section

Lithology

ALMEJAS
FORMATION



UNIVERSITY OF CALIFORNIA, RIVERSIDE

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO



SANTA BARBARA • SANTA CRUZ

DEPARTMENT OF GEOLOGICAL SCIENCES

RIVERSIDE, CALIFORNIA 92502

24 September 1965

To: Drs. H. Howard and S. Applegate

From: Richard H. Tedford

Re: University of California, Riverside collection of fossil birds and sharks from Cedros Island, Baja California.

The fossil bird and shark remains from the Pliocene "Salada Formation", Cedros Island, collected in 1964 and 1965 by parties from the University of California Riverside with the cooperation of the University of Baja California, Ensenada, are presented to the Los Angeles County Museum. The only condition of this donation is that U.C.R. may at some future date borrow some specimens for exhibit in its museum of geology. This collection is being placed at the Los Angeles County Museum so that recognized authorities on fossil birds and sharks may make maximum use of the material.

Notes on the collection.— The collection consists of float and in situ material, all unprepared, including five partial bird skeletons in plaster bandages. Only Glyptal was used as a hardener. I assigned field numbers to all specimens or suites of specimens from a single stratigraphic unit and locality. These are all recorded in my field notes (Cedros Island, 1965). A few comments on the geographic location of sites, stratigraphy and age of the deposits are necessary.

a.) Geographic location.— We were unable to secure adequate base maps of any type for Cedros Island, but air photographs will become available within a year and I will prepare a planimetric basemap showing the principal collecting sites from the photos. In the meanwhile, I have indicated the general locality for each field number. All of our marine vertebrate collecting was done in the basal part of the northwesterly dipping Pliocene section as it crops out in deep canyons and ridges near the base of the escarpment which forms the high northern wall of Valle Blanca. We covered about a half-mile of strike and three deep canyons which we named, from west to east, "Arroyo Esqueletos", "Arroyo Tiberon", and "Arroyo Delphin". Valle Blanca is a prominent east-west valley draining much of the southeast corner of Cedros Island, its mouth opens at the sea about 2 miles south of the cannery village.

b.) Stratigraphy.— Valle Blanca is cut in the brilliant white thinly bedded siltstones and sandstones of the Tortugas Formation (type locality: Bahia Tortugas on the south side of the Viscaino Peninsula, about 32 miles southeast of Cedros Island). The basal conglomerate of the steeply dipping Tortugas Formation rests unconformably on ochre-colored mudstones and sandstones of late Cretaceous age. At its type locality the Tortugas Formation

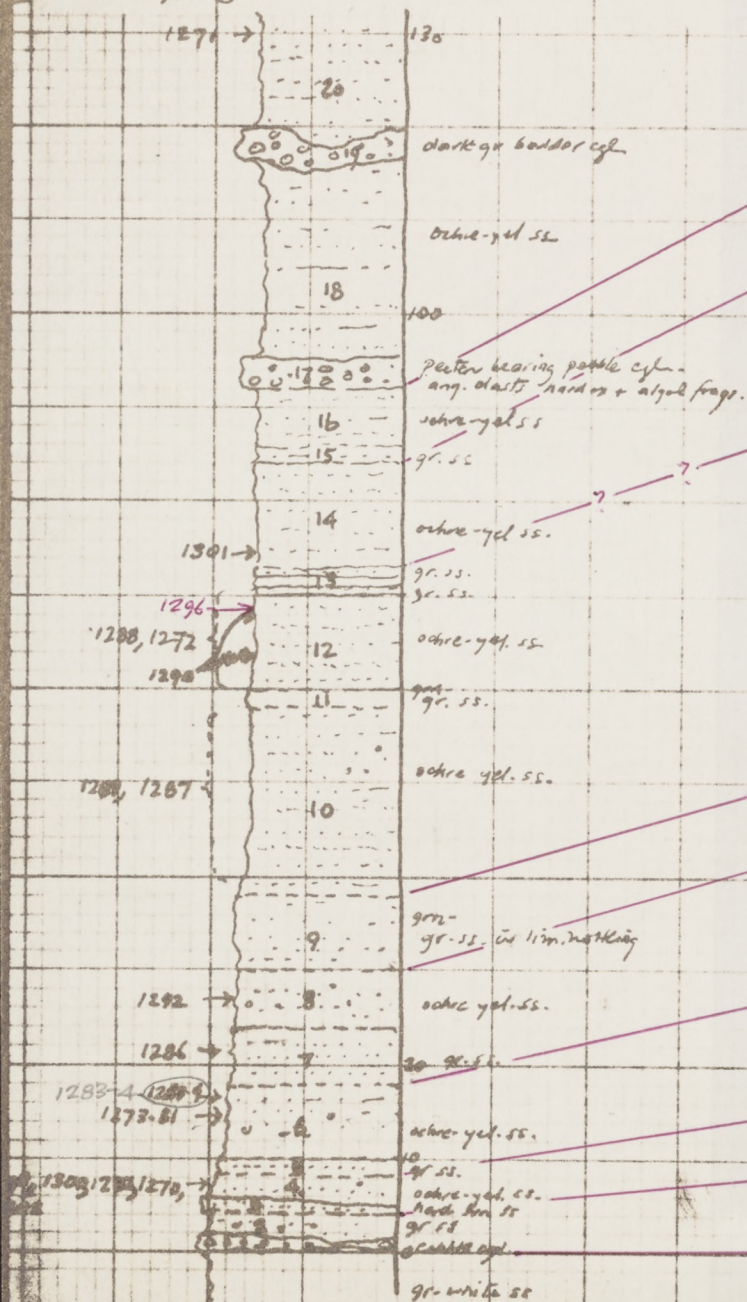
is of Temblor Age (late Miocene). Near the base of the escarpment which forms the north wall of Valle Blanca and extends northeast to the cannery village, the basal conglomerate of the Pliocene "Salada Formation" unconformably overlies the Tortugas Formation. The type locality of the Salada Formation occurs at Arroyo Salada near Bahia Almejas, about 340 miles southeast of Cedros Island. This name has been used for marine Pliocene deposits throughout Baja California thus assuming chronostratigraphic rather than lithostratigraphic significance. This is the reason I have placed the name in quotation marks. On Cedros Island the "Salada Formation" includes nearly 1000 feet of marine sandstone and conglomerate. The bulk of the vertebrate remains were collected from the lower 100-200 feet where interbedded ochre-colored and green-gray sandstones occur which are devoid of shelled invertebrate remains. A hard pebble conglomerate with pectens and algal fragments is the lowest invertebrate bed. We did little vertebrate collecting above the latter bed although there is some material from higher horizons among the specimens donated.

Attached are two columnar sections taken from my field notes of 1965. All specimens collected are located stratigraphically relative to one or the other of these columns. The correlation lines in red serve to relate the two columns; the numbers are my field numbers. Using the field numbers or the information on the paper labels with the material and the columnar sections the stratigraphic sequence of the material donated can be worked out. Note that in both columns the thicknesses are approximate. Do not use these columns in publication, I will send revised columnar sections as the data is worked up.

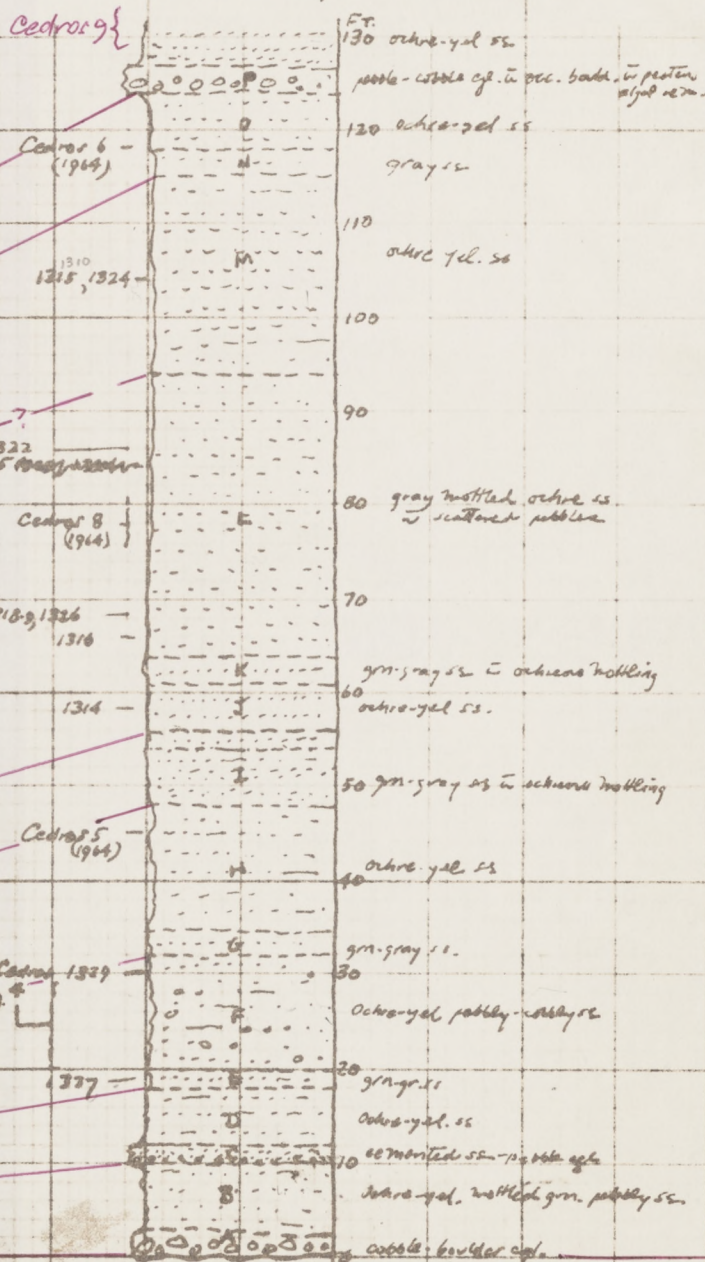
c.) Age.-- It is not possible at this stage to date the vertebrate bearing beds with any precision. Frank Kilmer (Humboldt State College, Arcata, Calif.) and C. Ray Givens (U.C.R.) studied the invertebrate stratigraphy in the field and their conclusion at that time was that the "Salada Formation" on Cedros Island is Pliocene and that the lower part including the vertebrate-bearing beds is probably no younger than middle Pliocene and my range as low as lower Pliocene based on comparison with assemblages from California.

Richard H. Jedford

Stratigraphic Column "Arroyo Esqueletos" (West) 15.
Through Loc 11 along
ridge 1 mi. N. to NE.
[Thickness approx.]



"Arroyo Delphin" (East) 33.
Stratigraphic Column
"Porpoise Canyon" Through
Kilmet "Discovery Locality". Thickness approx.



TORTUGAS
FM. - MIOCENE

"SALADA FORMATION" - PLIOCENE

The vertebrate faunas of the marine Cenozoic San Mateo Formation
in Southern California

by

Lawrence G. Barnes, J. Howard Hutchison,
Cammie Swift, and Bruce J. Welton.

Hildegarde Howard,

Intended to document the vertebrate faunas from the San Mateo Formation, in a general geologic guidebook. Systematic paleontology will be somewhat superficial, but detailed enough to substantiate identifications and to name two Local Faunas, one each for the lower and upper faunal zones. The geologic and stratigraphic treatment will be comparatively detailed. The paper will set the stage for more detailed systematic accounts of the fossil vertebrates which will be prepared by various authors. For example, H. Howard has a manuscript on the fossil birds, including some new taxa.

Manuscript Outline

Abstract

Introduction (Nomenclature of rock units, other rocks in area, refer to Woodford, 1925, history of collecting, significance of fossil assemblage geographically and chronologically, site location map, explain abbreviations in a sub-unit.

Acknowledgments.

Geologic and Paleontologic Context (Descriptive geology, stratigraphic columns, correlation, plot loc. stratigraphically, explain two local faunas, upper and lower bed, name them.

Systematic Paleontology

The Local Fauna from the lower horizon.

The Local Fauna from the upper horizon.

Conclusions

Literature Cited.

Contents

Abstract

Introduction

San Mateo Formation

Named by A. O. Woodford, 1925, p. 217 for nearshore marine shelf deposits consisting of arkoses and gravels, exposed north and east of the town of Oceanside, San Diego County, California.

Doubtfully correlated with the San Diego Formation by Woodford.

Not stated by Woodford to contain fossils. Fossils are exposed in quarries along Lawrence Canyon less than one mile northeast of Oceanside. Other exposures may lie on Camp Pendleton Marine Base.

Preliminary notice of occurrence of vertebrate fossils by Ken Frazier in Rocks and Minerals, 1969.

Field work 1969-1971 by UCMP parties, mainly J. H. Hutchison produced extensive collections.

Location map

Perhaps on a base of California map.

Description of formation and lithology

Fairly flat lying coarse white to gray sands ^{overlain by} ~~interbedded with~~ thick conglomerate units. Some exposures show yellow to red sands overlain by boulder conglomerates. Bones are commonly abraded and disarticulated in the conglomerates. Any associations that occur are in finer sandy units at the bottom of the section.

Descriptions of UCMP localities

San Mateo Fm. fauna listed from each locality and relative abundance, a chart?
Id. will usually be to genus in most cases.

Systematic, brief description of material referred to each taxon. Probably need only most diagnostic characters to assure the reader we know what we have. Illustrations may be presented (line or stipple) of the better preserved material. More exhaustive description will be presented by Howard (birds), Barnes and/or Repenning (pinnipeds), Barnes (cetaceans, Ph. D. dissert.).....

Composite faunal list from San Mateo Formation compared with one for San Diego Fm.

Conclusions ^{also Cedars?} ~~Many of the~~ ^{Birds,} ~~the same as for~~ ^{upper part of the} mammals, and sharks from the San Mateo Formation suggest an age ~~somewhat earlier than~~ ^{the same as for} the San Diego Formation, ~~early to Middle Pliocene to~~ ^{early to} Middle Pliocene. The vertebrates from the lower part are significantly older, older than the Almejas Formation or Isla Cedron, almost as old as vertebrates from the Santa Margarita Formation and correlative late Miocene, Clarendonian correlative rocks, and probably 9 million years old.

Literature Cited

Woodford, 1925
Frazier 1969
Menesini and Tavani, 1968
Shikama,
Baker and Domning, 1971?

Is it worth while INTRODUCTION
commenting on Vedde's view of Woodford's San Mateo formation as
"a channel deposit within the lower part of the Capistrano formation." (Vedde
1972
p. 167)

The name San Mateo Formation was first used by Woodford
(1925: 217) in his article on the San Onofre Breccia, ^{in which} Very
little mention was made of the San Mateo Formation which Woodford
grouped ^{it} among "Post-Capistrano Formations", and described ^{it consists of} as tilted
arkosic sands, gravels, ^cshists with rare fossils. Woodford indicated
that the formation ^{is} was doubtfully correlated with the San Diego
Formation, ^{is} questionably of Pliocene age, overlies the Capistrano
Formation, and is overlain by Pleistocene gravels and alluvium.
Outcrops of the San Mateo Formation were mapped by Woodford along the
south side of Arroyo San Mateo near San Onofre in San Diego County,
(pl. 24), on the east side of Aliso Creek 3 miles north of Dana
Point in Orange County (pl. 35), and in a strip along the sea coast
from south of San Juan Capistrano to the town of Oceanside.

Recently Frazier (1970) has reported the occurrence of sharks,
fish, birds, sea lions, and whales in gravel quarries in the San
Mateo Formation at Oceanside. The vertebrate fossils reported in
the present paper were collected at the site Frazier reported and
at other nearby localities in Lawrence Canyon and on both sides
of San Luis Rey River northwest of Oceanside. These localities
are at the extreme southern extent of Woodford's (1925: pl. 23)
mapped outcrop of post-Capistrano Formation (San Mateo Formation
and Pleistocene terrace) sediments.

Most of the localities are in gravel quarries and other man
made exposures. Fossils have been collected as surface specimens
that have been exposed by weathering. Bones and teeth are dis-
associated and scattered through the sediment laterally and vertically.
No quarries have ever been made for fossils because of the lack

of bonebeds, pockets, or other concentrations of bone.

At most of the Oceanside localities, well sorted, coarse, white quartz sand conformably overlies a reddish conglomerate that is coarsest at its base where granitic boulders are incorporated, and finer at the top. Fossil vertebrates are found in the white sand and in the red sand and finer gravel near the top of the conglomerate.

No invertebrate fossils have been found at the Oceanside outcrops of the San Mateo Formation. Several terrestrial mammal bones have been collected with marine vertebrates at the localities along the San Luis Rey River, to the north of the localities in Lawrence Canyon. The presence of large clasts and abraded bones, shells and absence of well formed bedding in the deposit indicate a high energy environment of deposition. These factors, plus the occurrence of land mammal remains suggest a near shore environment, and the ancient shoreline may have been located a short distance northeast of the Oceanside fossil localities.

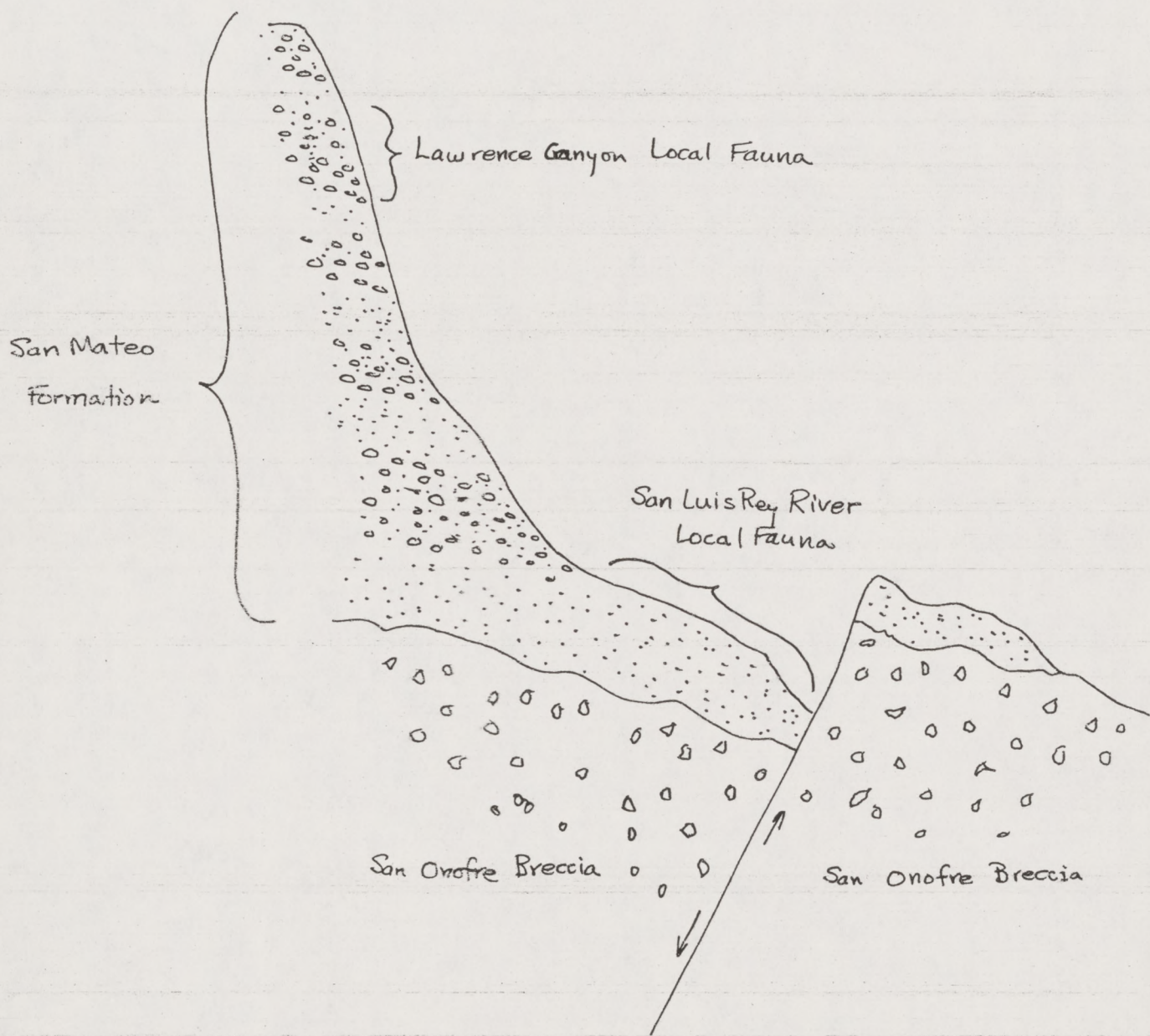
The known vertebrate fauna (see following list) differs from that of the San Diego Formation which is middle to late Pliocene in age. The differences in the two faunas indicate that the San Mateo Formation at Oceanside is older than the San Diego Formation exposed on San Diego Mesa. A tooth of Plihippus sensu lato has been recovered from the San Mateo Formation and a tooth of Equus sensu lato has been recovered from the San Diego Formation.

Teeth of Isurus cf. I. hastalis have been recovered from the San Mateo Formation and not from the San Diego Formation. The species of shark occurs in California in deposits ranging in age



Loc. 42 St.
V68145 4299
V68144 4298
12'30" 6880
Bill Walker's Locality.
4301
V68146
T. 11
23 MI. TO CAMP
SAN DIEGO JUNC.
75
68147
where
= 4297

Oceanside 7.5' USGS.



Generalized geologic section as exposed on northeast side of
quarry in Lawrence Canyon

from middle Miocene to early Pliocene.

Table Preliminary Vertebrate Faunal List for the San Mateo Formation.

Taxa are indicated by X for occurrence at a UCMF vertebrate locality.

Taxon	V-6880	V-6881	V-68106	V-68144	V-68145	V-68146	V-68147	V-68148	4297	4298
<u>Hexanchus</u> sp.				X				X		
<u>Isurus</u> cf. <u>I. oxvrhynchus</u>				X						
<u>Isurus</u> cf. <u>I. hastalis</u>		X		X	X					
<u>Carcharodon</u> cf. <u>C. sulcidens</u>	X	X	X		X		X	X		
Isuridae					X					
<u>Myliobatis</u> sp.				X	X					
Teleostomi			X	X	X					
Salmonidae	X				X		X			
Scianidae				X						
Serranidae				X						
Aves	X		X	X	X		X			
aff. <u>Phocoena</u>					X					
<u>Stenella</u> cf. <u>S. pliocenica</u>			X							
Delphinidae			X	X	X					
<u>Scaldicetus</u> cf. <u>S. grandis</u>						X				
aff. <u>Herpetocetus</u>					X					
<u>Balaenula</u> sp.	X									
<u>Arctocephalus</u> sp.				X	X					
Otariinae, large	X		X	X	X			X		
Odobenidae			X							
<u>Pliohippus</u>					X					
Artiodactyla					X					
Camelidae					X					
<u>Hydrodamalis</u>			X		X	X	X	X		

Fauna listed by locality

UCMP V-6880

?Upper beds.

Carcharodon cf. C. sulcidens
Salmonidae
Aves, undetermined
Mysticeti, undetermined
Balaenopteridae

UCMP V-6881

lower beds.

Carcharodon cf. C. sulcidens very common
Isurus cf. I. hastalis
Balaenopteridae

UCMP V-68106

Upper beds, cobbles.

Carcharodon cf. C. Sulcidens very common
Teleostomi spp.
Aves, undetermined
Odontoceti, Tursiops-sized
Delphinidae, undetermined
Balaenopteridae app.
Odobeninae
Otariinae
cf. Hydrodamalis cuestae Domning, ms. name

UCMP V-68144

lower white sands.

Isurus cf. I. oxyrhynchus
Isurus cf. I. planus
Myliobatis sp.
Teleostomi, spp.
Aves, undetermined
Delphinoidea, undetermined
Arctocephalus sp.
Otariinae undetermined

UCMP V-68145

Gray sands (=lower part?)

Isurus cf. I. hastalis
Carcharodon sp.
Myliobatis sp.
Isuridae, undetermined
Salmonidae, n. gen. n. sp. being described by another author
Teleostomi spp.
Aves, undetermined
Phocoenidae, undetermined
Stenella sp.
Delphinoidea
Balaenopteridae sp.
Arctocephalus sp.
Otariinae, large Eumetopias ?
Pliohippus
Camelidae
Artiodactyla
Hydrodamalis cuestae Domning, m. s. name

UCMP V-68146 Upper beds, cobbles.

Scaldicetus grandis (Du Bus)
cf. Hydrodamalis cuestae Domning, m. s. name

UCMP V-68147 lower white sands

Carcharodon cf. C. sulcidens
Salmonidae
Procellariiformes, undetermined
Balaenopteridae
cf. Hydrodamalis cuestae Domning, m.s. name

UCMP V-68148 Upper beds cobbles.

Notorhynchus sp.
Carcharodon cf. C. sulcidens
Balaenopteridae
Otariinae
cf. Hydrodamalis cuestae Domning, m.s. name (specimen missing)

aggregate
Preliminary ~~faunal~~ list, San Mateo ~~XXXXXX~~ Formation
(*Must be sorted into upper and lower Local Faunas.*)

Elasmobranchii

Notorhynchus

Isurus cf. I. hastalis

Isurus cf. I. oxyrhynchus

Carcharodon cf. C. sulcidens

Myliobatis

Teleostomi

Salmonidae

Aves

Procellariiformes

Mammalia

Odobeninae

Arctocephalus sp.

Otariinae, large, Eumetopias?

Delphinoidea

Stenella sp.

Phocoenidae

~~XXXX~~ Scaldicetus cf. S. grandis

Balaenopteridae

Plesiocetus

Artiodactyla

Camelidae

Pliohippus

Hydrodamalis cuestae Domning, m.s. name

The vertebrate fauna of the marine Pliocene San Mateo Formation
in Southern California

Patmahee

July 28, 1971

from P. B. B. B.
UCM 94720

by

Lawrence G. Barnes and J. Howard Hutchison and (?) Hildegard Howard

for PaleoBios

Intended to document the ~~first published account of~~ vertebrate fauna
from the San Mateo Formation.

Contents

San Mateo Formation

Named by A. O. Woodford, 1925, p. 217 for nearshore marine shelf deposits consisting of arkoses and gravels, exposed north and east of the town of Oceanside, San Diego County, California.

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Location map Perhaps on a base of California map.

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Fairly flat lying coarse white to gray sands interbedded with thick conglomerate units. Some exposures show yellow to red sands overlain by boulder conglomerates. Bones are commonly abraded and disarticulated. Any associations that occur are in finer sandy units.

Descriptions of UCMP localities

From UCMP locality files.

San Mateo Fm., fauna listed from each locality and relative abundance, a chart?
Id. will usually be to genus in most cases.

Systematic, brief description of material referred to each taxon. Probably need only most diagnostic characters to assure the reader we know what we have. Illustrations may be presented (line or stipple) of the better preserved material. More exhaustive description will be presented by Howard (birds), Barnes and/or Repenning (pinnipeds), Barnes (cetaceans, Ph. D. dissert.).....

Composite faunal list from San Mateo Formation compared with one for San Diego Fm.

Conclusions Many of the mammals and sharks from the San Mateo Formation suggest an age somewhat earlier than the San Diego Formation, early to Middle Pliocene.

Literature Cited

Woodford, 1925
Frazier, 1969
Menesini and Tavani, 1968

Fauna listed by locality

UCMP V-6880

Carcharodon cf. C. sulcidens
Salmonidae
Aves, undetermined
Mysticeti, undetermined
Balaenopteridae

UCMP V-6881

Carcharodon cf. C. sulcidens very common
Isurus cf. I. hastalis
Balaenopteridae

UCMP V-68106

Carcharodon cf. C. Sulcidens very common
Teleostomi spp.
Aves, undetermined
Odontoceti, Tursiops-sized
Delphinidae, undetermined
Balaenopteridae app.
Odobeninae
Otariinae
cf. Hydrodamalis cuestae Domning, ms. name

UCMP V-68144

Isurus cf. I. oxyrhynchus
Isurus cf. I. planus
Myliobatis sp.
Teleostomi, spp.
Aves, undetermined
Delphinoidea, undetermined
Arctocephalus sp.
Otariinae undetermined

UCMP V-68145

Isurus cf. I. hastalis
Carcharodon sp.
Myliobatis sp.
Isuridae, undetermined
Salmonidae, n. gen. n. sp. being described by another author
Teleostomi spp.
Aves, undetermined
Phocoenidae, undetermined
Stenella sp.
Delphinoidea
Balaenopteridae sp.
Arctocephalus sp.
Otariinae, large Eumetopias ?
Pliohippus
Camelidae
Artiodactyla
Hydrodamalis cuestae Domning, m. s. name

UCMP V-68146

Scaldicetus grandis (Du Bus)
cf. Hydrodamalis cuestae Domning, m. s. name

UCMP V-68147

Carcharodon cf. C. sulcidens
Salmonidae
Procellariiformes, undetermined
Balaenopteridae .
cf. Hydrodamalis cuestae Domning, m.s. anme

UCMP V-68148

Notorhynchus sp.
Carcharodon cf. C. sulcidens
Balaenopteridae
Otariinae
cf. Hydrodamalis cuestae Domning, m.s. name (specimen missing)

Preliminary faunal list, San Mateo ~~XXXXXX~~ Formation

Elasmobranchii

Notorhynchus

Isurus cf. I. hastalis

Isurus cf. I. oxyrhynchus

Carcharodon cf. C. sulcidens

Myllobatis

Teleostomi

Salmonidae

Aves

Procellariiformes

Mammalia

Odobeninae

Arctocephalus sp.

Otariinae, large, Eumetopias?

Delphinoidea

Stenella sp.

Phocoenidae

~~XXXXX~~ Scaldicetus cf. S. grandis

Balaenopteridae

Plesiocetus

Artiodactyla

Camelidae

Plihippus

Hydrodamalis cuestae Domning, m.s. name

Oceanside.

6880

68148

68106

Lawrence
Canyon.

red cgl.
ss.

Quarry

68146?

White
Sands

red cgl. ss.

water

68144, 68145

pat. red soils.

yellow-white ss, $\approx$ white ss

cgl.

$\approx$ red cgl. ss.

Schist + granite boulders.

① Calif. Div. Mines & Geol. Special Report 110

② and " 112 - 1974
Geol. & Engineering geologic aspects of the San Juan Capistrano
Quadrangle, Orange Co. Calif., by Morton Edgington & Donald L. Life

① Geology of the South-half of the El Toro Quadrangle
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② Geology & Engineering geologic aspects of the San Juan
Capistrano quadrangle, Orange Co. Calif. 1974
By Paul K. Morton & Wm. J. Edgington and
Donald L. Life

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Dr #2 Under Capistrano - OSO member - p. 46 Vert. equivalent common
late Mio. - early Plio. forams

Capistrano Tc - p. 44 - Contains Mio to Early Plio. forams.

Dr #1 p. 19 Capistrano given as late Mio. to Early Plio.
p. 20 " fm, OSO member - late Mio to Early Plio

Sept. 16, 1976

Dear Larry -

Mark This up as much as you wish
(I hope I may get the final copy typed
at KACM!).

Please pay particular attention
to the locality descriptions. I feel very
unsure in this regard.

I'll pick This up next week -
hope you will be there. Leave it for me
if you're not.

And thanks a million

Hildegard

Note the use of ^{spp.} for Diomedea and
Sulidae in list. I know there are two species
of Diomedea. The Sulidae, however, may
be just more elements of the species already
identified (above)

++

Berggren
1969

by

time in m. y.	HOLMES (1959)	KULP (1961)	EVERNDEN et al. (1961, 1965)	FUNNELL (1964)	Suggested boundaries correlations	radiometric and stage (this paper)
1	PLEISTOCENE	PLEISTOCENE	PLEISTOCENE	PLEISTOCENE (1.5)	PLEISTOCENE (1.8)	CALABRIAN
5	PLIOCENE	PLIOCENE	PLIOCENE	PLIOCENE (3.5)	PLIOCENE (5.5)	ASTIAN PIACENZIAN ZANCLIAN
10	(11)	(13 ± 1)	(12)	(7)	UPPER	MESSINIAN
15	MIOCENE	MIOCENE	MIOCENE	MIOCENE (12)	MIOCENE (10)	TORTONIAN
20	(25)	(25 ± 1)	(25)	MIOCENE (18)	MIOCENE (14)	LANGHIAN
25	(25)	(25 ± 1)	(25)	MIOCENE (19)	MIOCENE (14)	BURDIGALIAN
30	OLIGOCENE	OLIGOCENE	OLIGOCENE	OLIGOCENE (26)	OLIGOCENE (22.5)	AQUITANIAN
35	(36 ± 2)	(36 ± 2)	(33)	OLIGOCENE (31)	OLIGOCENE (32)	CHATTIAN
40	(40)	UPPER	(45 ± 2)	OLIGOCENE (32)	OLIGOCENE (32)	BORMIDIAN
45	EOCENE	EOCENE	EOCENE	EOCENE (36.5)	EOCENE (36)	RUPELIAN
50	(52 ± 2)	MIDDLE	(55)	EOCENE (38)	EOCENE (36)	LATTORFIAN
55	(58 ± 2)	LOWER	(55)	EOCENE (45)	EOCENE (45)	BARTONIAN
60	(60)	PALEOCENE	PALEOCENE	PALEOCENE (53)	PALEOCENE (53.5)	PRIBONIAN
65	PALEOCENE	PALEOCENE	PALEOCENE	PALEOCENE (54)	PALEOCENE (53.5)	LUTETIAN
70	(70)	(63 ± 2)	(67)	PALEOCENE (58.5)	PALEOCENE (60)	YPRESIAN
				PALEOCENE (65)	PALEOCENE (65)	THANETIAN
						MONTIAN s.s.
						DANIAN s.s.

C R E T A C E O U S

Table 2. CENOZOIC RADIOMETRIC TIME SCALE, CHRONOSTRATIGRAPHY, PLANKTONIC FORAMINIFERAL ZONATION AND DATUM PLANES (LEVELS)

RADIO- METRIC TIME SCALE (MY)	GEOMAGNETIC POLARITY HISTORY	CENOZOIC EPOCH SERIES	NORTH AMERICAN MAMMALIAN STAGES	WEST COAST (CALIFORNIA) MARINE STAGES	NEW ZEAL- LAND MARINE STAGES	80° - PALEOTEMPERATURE CURVE - NEW ZEALAND (CEVEREUX, 1967)	EURO- PEAN STAGES	CENOZOIC PLANKTONIC FORAMINIFERAL ZONES (BANNER & BLOW, 1965; BLOW, 1968; BLOW and BERGGREN, unpubl)		CENOZOIC PLANKTONIC FORAMINIFERAL DATUM PLANES
								PLIOCENE	PLIOCENE	
24		IRVINGTONIAN			CASTLE- CLIFFIAN	20° 15° 10°	CALAB- RIAN	N22	<i>Globorotalia truncatulinoides</i> P-R-Z	(185) <i>Globorotalia truncatulinoides</i> Datum
5		BLANCAN			NUKU- MARUAN WATOTAP- AN		ASTIAN	N21	<i>Globorotalia truncatulinoides</i> P-R-Z	(3) <i>Globorotalia truncatulinoides</i> Datum
10							PIACEN- ZIAN	N20	<i>Globorotalia truncatulinoides</i> P-R-Z	(3.7) <i>Globorotalia truncatulinoides</i> Datum
15							PIACEN- ZIAN	N19	<i>Globorotalia truncatulinoides</i> P-R-Z	(5) <i>Globorotalia truncatulinoides</i> Datum
20							PIACEN- ZIAN	N18	<i>Globorotalia truncatulinoides</i> P-R-Z	(9) <i>Globorotalia truncatulinoides</i> Datum
25							PIACEN- ZIAN	N17	<i>Globorotalia truncatulinoides</i> P-R-Z	(9.5) <i>Globorotalia truncatulinoides</i> Datum
30							PIACEN- ZIAN	N16	<i>Globorotalia truncatulinoides</i> P-R-Z	(10.5) <i>Globorotalia truncatulinoides</i> Datum
35							PIACEN- ZIAN	N15	<i>Globorotalia truncatulinoides</i> P-R-Z	(11.5) <i>Globorotalia truncatulinoides</i> Datum
40							PIACEN- ZIAN	N14	<i>Globorotalia truncatulinoides</i> P-R-Z	(12) <i>Globorotalia truncatulinoides</i> Datum
45							PIACEN- ZIAN	N13	<i>Globorotalia truncatulinoides</i> P-R-Z	(13) <i>Globorotalia truncatulinoides</i> Datum
50							PIACEN- ZIAN	N12	<i>Globorotalia truncatulinoides</i> P-R-Z	(14) <i>Globorotalia truncatulinoides</i> Datum
55							PIACEN- ZIAN	N11	<i>Globorotalia truncatulinoides</i> P-R-Z	(15) <i>Globorotalia truncatulinoides</i> Datum
60							PIACEN- ZIAN	N10	<i>Globorotalia truncatulinoides</i> P-R-Z	(17.5) <i>Globorotalia truncatulinoides</i> Datum
65							PIACEN- ZIAN	N9	<i>Globorotalia truncatulinoides</i> P-R-Z	(22.5) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N8	<i>Globorotalia truncatulinoides</i> P-R-Z	(26) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N7	<i>Globorotalia truncatulinoides</i> P-R-Z	(30) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N6	<i>Globorotalia truncatulinoides</i> P-R-Z	(32) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N5	<i>Globorotalia truncatulinoides</i> P-R-Z	(41) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N4	<i>Globorotalia truncatulinoides</i> P-R-Z	(45) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N3	<i>Globorotalia truncatulinoides</i> P-R-Z	(48) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N2	<i>Globorotalia truncatulinoides</i> P-R-Z	(52) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N1	<i>Globorotalia truncatulinoides</i> P-R-Z	(56) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N0	<i>Globorotalia truncatulinoides</i> P-R-Z	(60) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N-1	<i>Globorotalia truncatulinoides</i> P-R-Z	(61.5) <i>Globorotalia truncatulinoides</i> Datum
							PIACEN- ZIAN	N-2	<i>Globorotalia truncatulinoides</i> P-R-Z	(65) <i>Globorotalia truncatulinoides</i> Datum

Palaeomagnetic reversals are plotted at their assumed age interval. The relationship of palaeomagnetic stratigraphy to the biostratigraphic zonation based upon planktonic foraminifera remains to be verified, but is accurate down to about 5 million years on the basis of present data.

planktonic foraminiferal zones are recognized in the Cenozoic.

Current Views

Bandy⁷ attempted to relate Cenozoic planktonic foraminiferal zones to the radiometric scale, using Kulp's data⁸. Among his conclusions were: (1) The Palaeocene was about 5 m.y. (63 m.y.-58 m.y.). (2) The Eocene was about 22 m.y., divided in the following manner: Lower Eocene (Ypresian)—6 m.y. (58-52); Middle Eocene (Lutetian)—7 m.y. (52-45); Upper Eocene (Priabonian)—9 m.y. (45-36). (3) Oligocene: 8 m.y. (36-28). (4) Base Miocene (Aquitanian): 28 m.y.; (Miocene interval: 28-13 m.y.). (5) Base Pliocene—13 m.y.; (Pliocene interval—13 m.y.-3.5 m.y.).

I revised the dates for the Early/Middle and Middle/Late Eocene boundaries in a later version of this table¹¹. Dates of about 2 m.y. for the Pliocene/Pleistocene boundary and about 6 m.y. for the Miocene/Pliocene boundary were based on data not available to Funnell.

Changes from New Dates

The main revisions which can be made now are within the Miocene. On the basis of a date of 20.9 ± 1.5 m.y.¹² for the Obispo Tuff at the top of the Saucian Stage of California, I suggested an age of 21-22 m.y. for the *Globigerinita dissimilis* Zone of Bolli (N6 of Banner and Blow). (Ref. 13 suggested that the Obispo Tuff could be correlated with a bentonite bed at the top of the Saucian, immediately under Relizian strata that could be correlated

Table 3. LATE PALAEOGENE-NEOGENE RADIOMETRIC TIME SCALE, CHRONOSTRATIGRAPHY, PLANKTONIC FORAMINIFERAL ZONATION AND DATUM-PLANES (LEVELS)

TIME IN m.y.	1 EPOCH SERIES	2 N. AMERICAN MAMMAL. STAGES	3 W. COAST MARINE STAGES	4 PLANKT. FORAM. ZONES	5 CENOZOIC PLANKTONIC FORAM. DATUM PLANES	6 EUROPEAN STAGES	7 CORRELATION OF EUROPEAN STAGES WITH N.A. MAMMAL. STAGES BY VERT. PALEONTOLOGISTS
0	PLEISTOCENE	IRVINGTONIAN	HALLIAN	N23 N22 N21 N20	<i>G. truncatulinoides</i> (2)	CALABRIAN ASTIAN ZANCLIAN	VILLA-FRANCHIAN PLAISANCIAN ASTIAN
5	PLIOCENE	BLANCAN	WHEELERIAN VENTURIAN REPETIAN	N19 N18	<i>Sphaeroidinella</i> (5)	MESSINIAN	PONTIAN
10	LATE MIDDLE MIOCENE	HEMPHILLIAN	DELMONTIAN	N17 N16 N15	<i>Pulleniatina</i> (8)	TORTONIAN	
15	EARLY MIOCENE	CLARENDONIAN	MOHNIAN	N9 N8 N7	<i>Orbulina</i> (14)	LANGHIAN	SAR-MAT- IAN
20		BARSTOVIAN	RELI ZIAN	N6 N5 N4		BURDIGALIAN	VINDOBONIAN
25	LATE OLIGOCENE	HEMINGFORDIAN	SAUCIAN		<i>Globigerinoides</i> (22.5)	AQUITANIAN	BURDIGALIAN
30		ARIKAREAN		P22		CHATTIAN	AQUITANIAN
35		WHITNEYAN	ZEMORRIAN	P21	<i>G. angulatus</i> (30)	BORMIDIAN	CHATTIAN
40		ORELLAN		P20	<i>Pseudohastiger</i> (32) (extinction)	RUPELIAN	RUPELIAN
		CHADRONIAN	?	P19		LATTORFIAN	SANNOISIAN
		DUCHESNIAN	REFUGIAN	P18 P17 P16	<i>Hontkenia</i> (36.5) (extinction)	PRIABON- IAN BAR- TONIAN	LUDIAN

The relationship suggested by Bandy between biostratigraphic intervals and time-stratigraphic units was, however, wrong in some instances. I have discussed these correlations elsewhere⁹.

I have also attempted¹⁻² to relate Cenozoic planktonic foraminiferal zones and geological stage units to a radiometric scale, from a comprehensive analysis and evaluation of the data on radiometric dating in Cenozoic marine and non-marine sections. Biostratigraphic correlation between marine and non-marine sections gave a table which purported to show suggested relations between a Cenozoic radiometric time scale, chronostratigraphic boundaries and planktonic foraminiferal zones. In general, the age determinations of major geological boundaries in the Cenozoic agreed with those suggested by Funnell¹⁰.

with the *Globorotaloides* (or *Globigerinita*) *stainforthi* Zone.) I also followed the tacit assumption of most investigators that the 25-26 m.y. date used by vertebrate palaeontologists to date the base of the Arikarean Stage, which they correlate with the Aquitanian Stage, did indeed represent a date at the base of the marine Aquitanian. The Committee on Mediterranean Neogene Stratigraphy has recommended¹⁴ that the Oligocene/Miocene boundary should be drawn at the base of the stratotype Aquitanian, which corresponds to the first evolutionary appearance of the planktonic foraminiferal genus *Globigerinoides*. Accordingly I used a date of about 26 m.y. here.

In an article dealing with the biostratigraphy of Miocene sediments on the East Pacific Rise, Burrell *et al.*¹⁵ estimated the age of the basement in core V20-80 at 22 m.y.

(based on magnetic anomalies). They showed that the fauna at the bottom of the core was slightly older than the *Orbulina* Datum (probably in zone N8) and suggested an age of 20 m.y. for the *Orbulina* Datum. I used this date for my original table¹⁶, but changed it to 18.5 m.y. in a later version¹⁷.

Two lines of evidence now make possible a further refinement of these two dates in the Miocene. First, a series of radiometric measurements in the California Miocene¹⁸ has yielded boundary dates for Zemorrian/Saucesian, 22.5 m.y.; Saucesian/Relizian, 15.3 m.y.; Relizian/Saucesian, 13.7–14.5 m.y.; and Lusian/Mohnian, < 13 m.y. The significant facts here are that the Zemorrian/Saucesian boundary corresponds to the base of the *Globorotalia kugleri* Zone of Bolli (Zone N4 of Banner and Blow¹⁹). This is the level of the first evolutionary appearance of *Globigerinoides*, which denotes the base of the Aquitanian Stage and the Oligocene/Miocene boundary. The revised dates of 15–16 m.y. on the Obispo Tuff¹⁸ and the date of 15.3 m.y. for the Saucesian/Relizian boundary allow an estimate of about 15 m.y. for Zone N7 (see Table 3). The Relizian/Lusian boundary approximates very closely to the first evolutionary appearance of *Orbulina* (base Zone N9) and provides for it an estimated date of 14 m.y. It is interesting that estimates based on the rates of sea-floor spreading in the North Atlantic suggest that the *Orbulina* Datum, which was cored in contact with basement on the second leg of the current JOIDES deep sea drilling programme, should be about 13–14 m.y. (J. D. Phillips, personal communication).

Table 4. SUMMARY OF ESTIMATED AVERAGE DURATION OF CENOZOIC PLANKTONIC FORAMINIFERAL ZONES IN RELATION TO CHRONOSTRATIGRAPHIC UNITS

Unit	M.y.	Estimated average length of zones (m.y.)
Cenozoic	65	1.51
Palaeocene	11.5	2.3
Eocene	17.5	1.6
Early Eocene	4.5	1.1
Middle Eocene	4	0.8
Late Eocene	9	3.0
Oligocene	13.5	2.7
Miocene	17	1.1
Early Miocene	8.5	1.7
Middle Miocene	4	0.7
Late Miocene	4.5	1.5
Pliocene	3.5	1.2
Neogene	22.5	1.12
Palaeogene	42.5	1.93

The second line of evidence comes from the results of leg 3 of the JOIDES deep sea drilling programme. Seven holes were drilled across the flanks of the Middle Atlantic Ridge in the South Atlantic at about 30° south latitude. When the distances from the ridge axis were plotted against the estimated age of sediment/basement contact the seven sites fell nearly on a straight line (personal communication from A. Maxwell and R. von Herzen). Site 15, in which Zone N5 was found in contact with basement, lies on the line at about 20 m.y.; Site 18, in which the base of Zone N4 (*Globigerinoides* Datum) was found in contact with basement, also falls directly on the line at 22.5 m.y. Site 17, in which the lower part of Zone P21 was found in contact with basement, falls on the line at about 33 m.y. These data suggest that sea-floor spreading occurred at a uniform rate during the Oligocene–Miocene and that the dates discussed here are very close to the absolute dates for these biostratigraphic datum levels.

Palaeomagnetic stratigraphy has proved useful in determining the ages of biostratigraphic levels and chronostratigraphic boundaries. Cox²⁰ has summarized

recent work on the palaeomagnetic time scale for the past 5 m.y., and Hays *et al.*^{21,22} have discussed the relationships between the palaeomagnetic time scale and biostratigraphic datums in the Pliocene and Pleistocene. Their data, together with data obtained at the Woods Hole Oceanographic Institution^{23,24}, have formed the basis for the construction above 5 m.y. in Table 2.

Effects of Revision

Table 2 represents an attempt, based on current data, to relate Cenozoic biostratigraphic levels, chronostratigraphic Datum planes and geological boundaries to an absolute time scale. Table 3 suggests a correlation of Late-Eocene–Pleistocene chronostratigraphic units with the radiometric scale. Significantly, the vertebrate palaeontologists' correlation of the standard non-marine sections of California with the non-marine equivalents in Europe (right-hand column) does not correspond to the limits of the European marine stages. For example, the Arikarean Stage in California is dated at about 21–26 m.y. and correlated with the Aquitanian and the lower part of the non-marine Burdigalian in Europe. A closer look at the time-stratigraphic limits of the marine Aquitanian Stage reveals, however, that the base of the Aquitanian is at about 22.5 m.y. (based on its correlation with the base of the Saucesian Stage in California) and that the top of the Aquitanian is at about 17 m.y. The Arikarean therefore corresponds largely to the late Chattian and earliest Aquitanian. Similar instances of inaccurate correlation may be seen by comparing columns 2 and 7 with column 6.

We can now construct a reliable radiometric time scale for the geological past, in particular the Cenozoic Era. It is possible to place within a time framework biostratigraphic Datums, first appearances and extinctions of fossils species, and changes in coiling direction, as well as the rates of organic evolution in various fossil groups. The transition from a purely descriptive to a more quantitative study of Earth history is thus well on the way to becoming established.

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¹⁶ Berggren, W. A., *Proc. SCOR Conf., Cambridge, 1967*, Fig. 39 (Cambridge Univ. Press; in the press).

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¹⁹ Blaut, G., and Kleinpell, R. M., *Contr. Cushman Found. For. Res.*, 20, 7 (1969).

²⁰ Cox, A., *Science*, 163, 237 (1969).

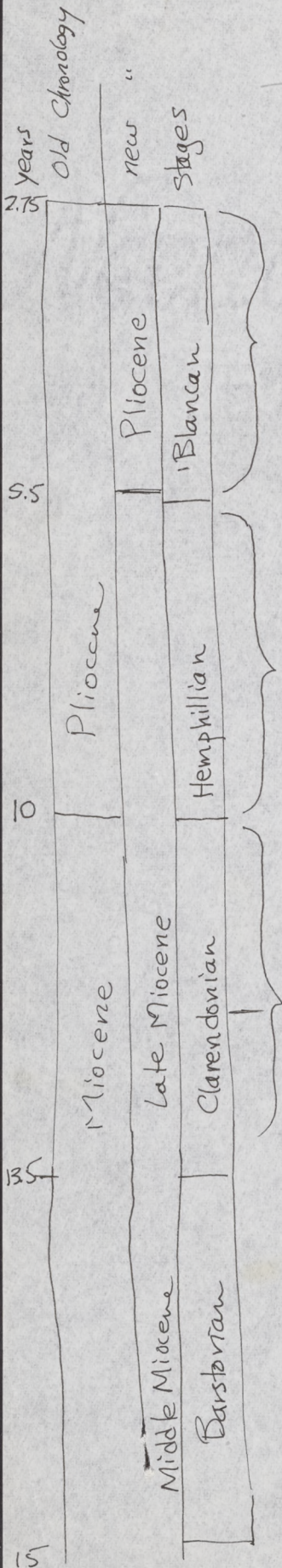
²¹ Hays, J. D., Saito, T., Burckle, L. H., and Opdyke, N. D., *Geol. Soc. Amer. Abstr.* 1968 Ann. Mtg. Mexico City, 131 (1968).

²² Hays, J. D., Saito, T., Opdyke, N. D., and Burckle, L. H., *Geol. Soc. Amer. Bull.* (in the press).

²³ Berggren, W. A., Phillips, J. D., Bertels, A., and Wall, D., *Nature*, 216, 253 (1967).

²⁴ Phillips, J. D., Berggren, W. A., Bertels, A., and Wall, D., *Earth and Planet. Sci. Lett.*, 4, 118 (1968).

Note: Pomita Mail K - Arrived at 3 m.y.
 Oligocene, 1965" Age of the marine Pliocene
 of Calif., Bull L.A.P.G. 42(7): 1087 abstract.
 Reported in Science, January 1974 p. 65



San Diego Fm.
 Fernando Fm. (1067) = Pico Fm. (forams at 1067)
 Upper Capistrano Fm. in Mission Viejo.

Cedros ^{Mammals}
 Lower Capistrano (Oso Member, Leisure World Locs. 65120, 65121,
 Older rocks at Oceanside (white sands) = San Mateo? - ^{Suggest Mammals called} Mammals
 Purisima Fm.

Valmonte Diatomite in Palos Verdes
 Monterey Fm. 6906, 6909 in Laguna Niguel 1945, lower
 Modelo Fm.
 Tepusquet.
 Lompoc. etc.

Sharktooth Hill.

M. milleri
 M. diegensis
 M. calif.
 ? Praemacalla sp.
 Praemacalla
 P. wetmorei
 Praemacalla
 lagunensis
 degeneration

Almejas Fm.

uncon.

uncon.

= San Diego Fm. $\approx$ mollusks.
= Blanton = 3.3 - 1.7 my.

Barnes 1974 says
3-5 my. for
San Diego Fm.

100 ft

< 3.3 my.

= Capistrano
Purisima

vertebrates > 12 my.

= 4-10 my.

$\approx$ Hemphillian
vertebrates.

15

Tortuga Fm.

Trembler Molluscs.
= 12-15 my.

~~LATE Oligocene or~~Late Eocene or Early Oligocene

He stated the source leads to be of late Upper Eocene or Lower Oligocene age. In a

table on p. 266 of the same publication he

^{Oligocene age} Kellogg (1936:258) reported an unidentified ~~ed~~ archaeocete of early ^{from} the west side of Vancouver Island, British Columbia, Canada, based upon an incomplete vertebra. ~~Later (1936: 266) Kellogg~~ gave the age as late Eocene, however. The subordinal allocation is undoubtedly correct, but because of the taxonomic and geologic uncertainties regarding the specimen it will not be considered further in this report. The occurrence does point out the existence of ~~ex~~ cetaceans in the North Pacific Ocean prior to the late Oligocene.

On p. 272 (Table 70) Kellogg lists an Archaeocete from the Lower Oligocene of Vancouver Island.

Plioc.

7

9 Capistrano Fm

Hemphillian

late
Mioc.

10

11

Monterey Fm upper

Autonetics, 6906

Clarendonian
1945, etc.

Mid.
Mioc.

12

Fm

14

15

lower

Barstovian
Pecten Reef
14 m.y.

Early
Mioc

~~Agave~~

Lewett
Sand

"Vagueros"

Arikarean
Pyramid
Hill

22

	Sharktooth Hill	Laguna Hills L.A. Co. 1945	Laguna N. Fuel 1906 et al	San Mateo Is.	Adios Id.	La Jolla Wald 7053, 3183, 65120-21	Mission Vieja	Escamela	San Diego	1945
Diomedea	californica milleri	spp. 2 ident?	californica? sp.?			Sp.?				
Puffinus	inceptor priscus mitchelli	priscus? calhouni sp.?	niguelensis		sp? Bedfordi	Sp. try Kauaiensis		felthami	Kauaiensis	
Gavia			brooksii (sued)	sp. (medium)		Sp.?			concolor? howardae	
Oceanodroma			sp.							
Osteodroma	sp.	sp. sp.	arri			subsp. sp.			humilis	
Sula	magabanda		sp.			sp.				
Morus	vagabunda sp.?	longicauda?	longicauda magnus n. sp.		m. sp.?					
Miosula		sp.?	media?						recentia	
Miosula		sp? = S. willetti?								
Paleosula										
Megapodolobus					opifonus?	sp.?				
Presbycus	abatus	abatus				goose sp.				
Branta	sp.								shorebird sp.	
Recurvirostris	sp.									
Alcidae	Alca sp. Certhia sp.	Alca m. Certhia sp. Aethya rossi sp.	Alca? Certhia? Aethya? Heterocercus sp.	Alca? n. sp. Alcidae sp.	Certhia minor	sp. 203				
Mancallinae		Alcedo ulmifera						Alcedo	M. diegensis M. mulleri	
		P. lagunaensis	P. wetmorei	P. wetmorei?	Mancalla cedraensis	Mancalla diegensis M. mulleri	Mancalla diegensis M. mulleri	M. calif.	M. diegensis M. mulleri	
↑ Grebe st. m. l.						sp.			parvus? subparvus m. sp.	

	Lumpka	Stamm. mtb.	Tepusquet	Lomita	San Juan Capistrano Capistrano fm
Diomedea	—	—	—	sp.	
Puffinus	diatonicus	diatonicus sp.	sp.	diatonicus	
Gavia					
O. leucostictus O. leucostictus	—	—	—	—	O. heubaldi
Ostodontornis		ovii	ovii type		
Sula	willesti	pohli willesti			
Morus	longicauda			sd	
Pelecanus				strochovi	
Phalacrocorax		femoralis			
Alcedo	cerulea dubia				

Late
Moreau

July 1977

check Puffinus bones from 65/20, 21, 3183
with kaulahopi + felthami

check Maucalla carpi from 65/20-21
with M. calq. vs M. defuss
+ cedroensis

check see new Mission Viejo materials
get loc. nos. + sites

Oryzopsis

65/20 + 65/21

Podiceps

San Diego
parvus?
austriacus

Phalaropus

S.F. Valer
leucostictus

San Diego
hemmelii

Oreoscoptes

Californicus from 65/20
O. flabellifrons

Late Neogene Microplanktonic Time-Scale Chapter 2 - in
Berggren & VanCouvering Palaeo Vol. 16 no 1/2 Oct. 1974
Special Issue "The Late Neogene."

1st appearance of Orbulina is within the Lower Luisian Stage in Calif.
Thus within the S. heteromorphus (NNS) Zones. Base of Luisian
estimated at 13.9-14.5 m.y. - or 14 m.y. (approx base)

Base of Relizian 15.3 m.y. - correlation with Zone N7
Thus Relizian ^{would} encompass zones N7 (part at least) and N8
and span the interval 15.3 - 14 m.y.

Luisian/Mohamian boundary younger than 13 m.y.
Zones N10 + N11 are short (combined duration 0.3 m.y.)
whereas Zones N9 + N12 are relatively longer. Zone N12
may have been 0.5 m.y. in duration

Tortonian/Serravalian boundary - Tortonian base
older than 9.5 m.y. The boundary lies within Zone N15
according to Cita & Blow 1969 but others say the boundary is
within Zone NN9

Calif. boundaries @ Turner 1970 give 11-11.5 m.y. for base
of Tortonian

Tortonian/Messinian boundary - ^{between zones N17 and NN11} Magnetic Epoch 6/7 at
6.6 m.y. (Radiometric dates 8-6.6 m.y. for lower Messinian of Morocco)

Mohamian/Delsmontian boundary. ~~base of Delsmontian 6.6 m.y.~~
Mohamian in Calif. spans 6-7 m.y. time interval corresponds to
Zone N11 - N14 + lower half of N17, (= Sancerian Stage East (Mio))

Miocene/Pliocene boundary 5 m.y. In Calif. the
boundary is within the Delsmontian stage. The limits of
which span the interval 6.25 m.y.

Miocene/Pliocene boundary estimated by some to be 2.7-3.0 m.y. BP
& by others as old as 15 m.y. Most rec. paleontologists place
it at 10-12 m.y. based on 1st appearance of Hippurion in Pontian
of Mediterranean at that time. Marine paleontologists place
the Mio/Pliocene boundary (Medit.) as younger than 6 m.y. or 5 m.y.

Plio/Pleistocene boundary estimated by
Turner 0.6 m.y. to 3.5-4 m.y. (East Paleos)
1.8 m.y. Berggren

Berggren
question
this

Plio/Pleist boundary in Calif. correlated to Philippine
Sphaeroidinella delticum was 9. m.y. based on date in upper
 Malaga mudstone (Belmontian) of Malaga Cove, So. Calif.

Plio-Pleist boundary defined (traditionally) by
 a shift from dextral (late Plio) to sinistral (early Pleist)
 populations of *Globiferina pachyderma* (So. Calif.)
 Age of 3 m.y. (K-AR date) of Lomita Marl was suggested
 for this level. Pliocene spanned 9-3 m.y. on this basis.
 Others buy the Plio/Pleist boundary up to 1.5 m.y.

Pleist 0.6 m.y.	- the major continental glaciation in Europe
Blancan 2.5 m.y.	Elephantidae appear in Europe (Early Villafranchian)
Hemphillian / Belmontian 4 m.y.	microtine rodents in SW Europe
5 m.y.	Mediterranean Basin inundated
Clarendon / Maastricht 0 m.y.	cool, summer-dry climate in temperate regions (Turolian)
2 m.y.	modern rodents in Paleo Medit. area (Early Vallesian)
2.5 m.y.	Hipparchia appears in Paleo Medit. (earliest Vallesian)
Barstovian / Luskian 4 m.y.	Isolation of Paratethyan basin (earliest Denertian)

From "The Late Neogene" by W.A. Berggren & J.A. Van Couvergne.
 in *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 14 nos 1-2, Oct 1974, 216 pp.
 Pliocene / Pleistocene (base Calabrian); ca 1.6 - 1.8 m.y. 2.5
 Early / Late Pliocene (Zanclian / Placenzian); ca 3.3 m.y. ?
 Miocene / Pliocene (Messinian / Zanclian); ca 5.0 m.y. 7 m.y.
 [Late / Late / Late Miocene] (Tortonian / Messinian); ca 6.6 m.y. Baudy & Ingle 9 m.y.
 Middle / Late Miocene (Serravallian / Tortonian); ca 10.5 - 10.7 m.y. 14 m.y.
 Evernden figures

not
 so stated
 by authors
 [inserted by H]

Jack F. Evernden & Royce K. Smith "The Cenozoic Time Scale"
 Geol. Soc. Amer. Spec. Paper 124 [Radiometric Dating
 and Paleontological Zonation, edited by Orville L. Bard]

Base of Calabrian: ca. 2.5 m.y. Zanclian 2.5 m.y.
~~Zanclian / Placenzian~~ Top of ~~astase~~
 Messinian / Zanclian 7 m.y. Top of Messinian ca 7 m.y.
 Tortonian / Messinian 14 m.y. Top of Tortonian ca 14 m.y.
 Top of Burdigalian ca 18 m.y.

Baudy & Ingle Miocene / Pliocene boundary date of 9.9 m.y.
 based on a glass date on an ash bed in uppermost Miocene in Calif.

Lensian forams on Via Puerta Lersail Wald

Magnetic Polarity Stratigraphy of Pliocene-Pleistocene Terrestrial Deposits and Vertebrate Faunas, San Pedro Valley, Arizona

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ABSTRACT

Horizontally stratified magnetic zones are observed throughout the Pliocene-Pleistocene valley fill of the upper San Pedro Valley, Arizona. Within one detailed 150-m stratigraphic section (Curtis Ranch), twelve superposed magnetic polarity zones are identified spanning the time from the upper Gilbert Epoch through the Brunhes Epoch. These magnetic polarity zones extend over a 64-km stretch of the valley and serve as convenient chronostratigraphic units. Based on the position of mammalian fossils within the chronostratigraphic zones, we have defined four mammal datum planes for the upper San Pedro Valley, including the first appearance of *Lepus* sp. at 1.9 m.y. *Lepus* sp. marks the first occurrence of a definitive Irvingtonian land mammal in the San Pedro Valley and thus places the local boundary of the Irvingtonian Land Mammal Age shortly below the Olduvai event. This position equates approximately with the Pliocene-Pleistocene boundary of the pelagic marine record. *Key words:* geochronology, stratigraphic paleontology, mammalian paleontology, paleomagnetism.

INTRODUCTION

Cenozoic chronology was founded on biostratigraphy, with a terrestrial system based on specific events of mammalian evolution, and a comparable marine system based on molluscan or foraminiferal faunal events. The correlation of continental and

marine strata is difficult because these mutually exclusive environments of deposition preclude the frequent interdigitation of diagnostic faunas and floras. As a consequence, resolution within and between the continental and marine records has reached its practical limits with conventional biostratigraphic correlation techniques. Within the pelagic marine record, however, correlations have been refined to a remarkable extent in recent years. This has been possible because of the sudden development of magnetic polarity stratigraphy as an accurate absolute correlation tool (Opdyke, 1972). The success of remanent magnetic studies in defining the stratigraphy of pelagic sediments has invited its use on other sediment types, especially terrestrial sedimentary deposits. If, indeed, mammal-bearing terrestrial deposits are generally amenable to the techniques of magnetic polarity stratigraphy, then intercontinental scale, absolute-time correlations with the marine record are possible. This development would then make possible the combination of all the relevant marine and continental data into a comprehensive chronology. The present study is one step to this end, specifically, the magnetic polarity stratigraphy of a well-known, mammal-bearing deposit in North America.

Magnetic polarity stratigraphy has been extensively used on sequences of volcanic rocks (Roche, 1950, 1951; Hospers, 1954; Rutten and Wensink, 1960; and many others), but its use in terrestrial sedimentary deposits has been rather restricted. Russian workers were among the first to use the

technique in the Pliocene and Quaternary sections of western Turkmenia (Khramov, 1958). Other noteworthy studies on terrestrial sediments include those by Griffiths (1955), Bucha and others (1969), van Montfrans and Hospers (1969), van Montfrans (1971), and Wensink (1972). This study serves to extend this type of work to the valley-fill sediment of western North America.

GEOLOGIC SETTING

The San Pedro Valley near Benson, Arizona, consists of a typical basin in the Basin and Range province with a valley fill of Miocene-Pleistocene age. The deposits of the upper San Pedro Valley were studied by Gray (1967), who defined and named the St. David Formation. The St. David comprises a diversified valley fill more than 180 m thick consisting of lacustrine, swamp, and fluvial deposits in a complex mixture of lithologies including gravel, silt, clay marl, and paleosol deposits. Gray (1967) divided the St. David Formation into three members. The lowest member consists of unfossiliferous red clay and silt, sometimes gypsiferous; the middle member contains primarily lacustrine and paludal strata and bears most of the fossil record. The upper member marks a distinct change in sedimentary regimen, with a conspicuous absence of marl and clay and the presence of sand, gravel, and thick paleosol deposits. The St. David Formation was subjected to mild local deformation and a rather extensive phase of erosion following its deposi-

tion. This erosion has incised a considerable relief onto the former landforms. The episode of erosion was accompanied by a pervasive gravel veneer deposited over the St. David Formation. The term "granite wash" is informally used to depict this gravel layer. The upper surface of the granite wash layer forms the "Whetstone Surface" of Bryan (1926; Gilluly, 1956). Lastly, the Whetstone Surface has been subjected to local degradation and aggradation, leaving irregular lenticular bodies of marl, gravel, and soil over the Whetstone Surface (Haynes, 1967).

Intermittently, ash beds are found within the St. David Formation. These ash deposits represent several volcanic episodes that

have been described by Scarborough (1974). The surficial deposits described by Haynes (1967) fall largely in the C^{14} dating range.

The present San Pedro River courses through the valley from south to north and is cutting an erosion scarp into the older Whetstone Surface. This scarp and its associated badlands afford the best natural outcrops of the St. David Formation. It is also in this scarp-badland zone that most vertebrate fossils are found.

PALEONTOLOGY

Vertebrate fossils were discovered in the San Pedro Valley in 1920 by Kirk Bryan. Fossils were subsequently collected and studied by Gidley (1922, 1926), Gazin (1942), and Lammers (1970). Surficial deposits in the San Pedro Valley were studied by Haynes (1967), who compiled the record for the late Pleistocene (Rancholabrean Land Mammal Age) fauna.

Gidley (1922) described and named the Benson and Curtis Ranch faunas in the San Pedro Valley. He recognized that these faunas are slightly different in age, even though they are nearly from the same stratigraphic level and have structural similarities. Gazin (1942) reported that the Benson fauna falls definitely in the Blancan Land Mammal Age (late Pliocene) and agreed that the Curtis Ranch fauna is younger than the Benson fauna. Savage (1951) proposed a new land mammal age, Irvingtonian, for post-Blancan and pre-Rancholabrean faunas. Since 1951 the Curtis Ranch fauna has generally been considered to fall within the Irvingtonian Land Mammal Age.

Thirteen fossil sites in the San Pedro Valley have been selected here for faunal analysis. Fifty-four fossil mammal taxa (listed in Table 1) represent the known faunal record for the 13 sites. These sites were also sampled and analyzed for their paleomagnetism and their position on the magnetic time scale (Cox and others, 1964). The Post Ranch site corresponds to the Benson fauna of Gidley and Gazin. The Gidley site and Glyptotherium site correspond to the Curtis Ranch fauna of Gidley (1922).

METHODS AND MATERIALS

Paleomagnetic samples were taken from 160 sites along 40 mi (64 km) of the upper San Pedro Valley. However, a major effort was concentrated in the area where the Curtis Ranch fauna occurs. Here a long, rather continuous exposure of rocks provided us with our longest and most complete record. Our final sample suite at Curtis Ranch consisted of 81 sites, with some 240 samples, averaging about 3.3 m in ver-

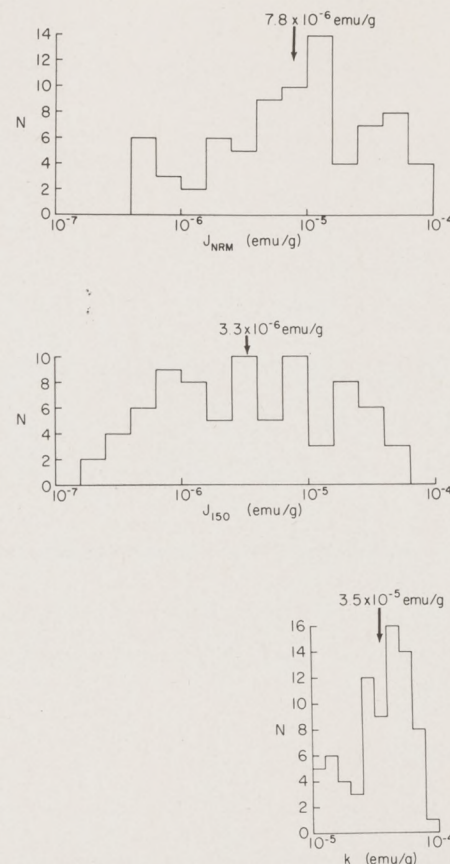


Figure 2. Histograms of natural remanent magnetization (J_{NRM}), intensity of magnetization after demagnetization in 150 oe (J_{150}), and susceptibility (k). Based on 78 specimens from the Curtis Ranch section. Geometric means appear above arrows.

tical separation when replication is accounted for. About 150 m of stratigraphic section is represented by this sample suite. On a similar but less intense scale, all the better-known fossil localities in the upper San Pedro Valley were sampled and studied to establish their magnetic-stratigraphic position.

Each site was sampled by taking three separately oriented specimens at three distinctly separated locations within a sedimentary unit. This sampling procedure is the minimum that will assure good site statistics and unambiguous polarities. The magnetic data reported in this study are for the most part derived from three measurements per site. In some cases, however, fewer measurements were made because of problems such as sample disintegration.

The preferred lithology for magnetic sampling is clay, which composes the bulk of samples collected. However, silt and, more rarely, sand and marl were also collected when suitable clay material could not be obtained. Specimens were oriented in the field by filing a horizontal or vertical plane on the specimen with hand rasp; a magnetic vector (measured by Brunton compass) was

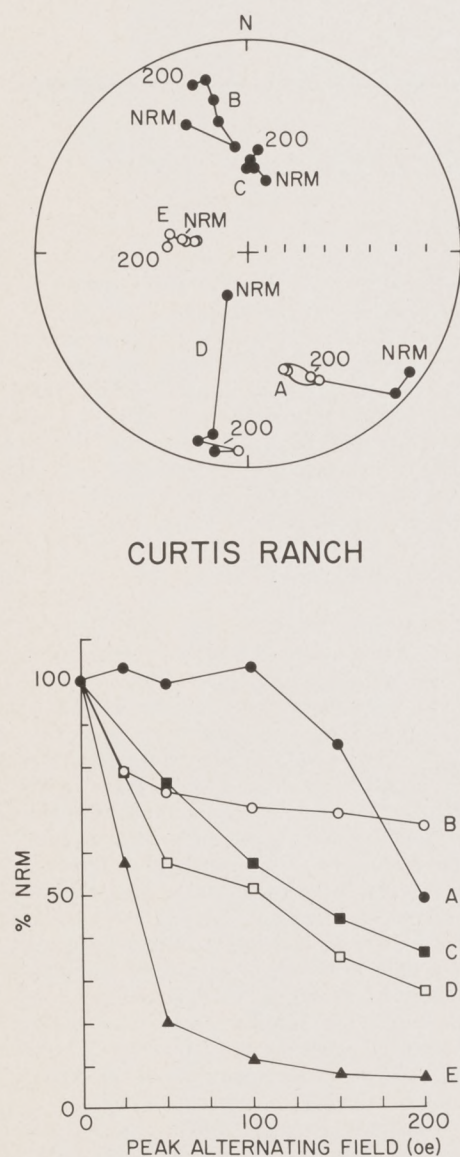


Figure 1. Progressive change in direction of magnetization with increasing alternating fields for selected samples plotted on stereographic projection (top). Filled circles are lower hemisphere projections. Alternating field demagnetization curves for same samples (bottom).

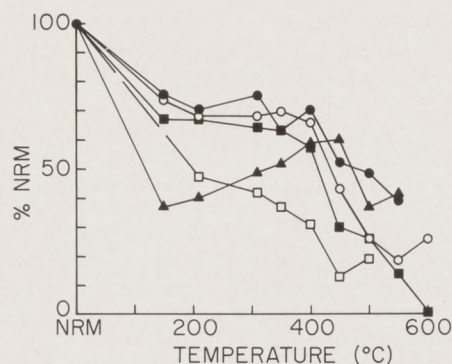


Figure 3. Thermal demagnetization curves for selected samples.

inscribed on the plane. Samples were then broken from the outcrop and sent to the laboratory. There the samples were sized and shaped to fit the magnetometer sample compartment by sawing and finally by grinding on a disk sander. The error associated with these consecutive mechanical operations is considered $\pm 5^\circ$ in both declination and inclination.

Samples were selected in the field by their stratigraphic position, lithology, and state of weathering. In deeply weathered outcrops, hand excavations were made to obtain fresher sample material. Along with collections of the magnetic samples, a detailed description and measurement of the stratigraphy was made. Elevation measurements were made by hand leveling between bench marks or reliable topographic datum points. The entire section was "walked out" by means of convenient marker beds, usually marls. In this terrane and climate, the marl units characteristically form conspicuous ledges or surfaces. Initial dip measurements were made by plane table methods. The maximum measured dip was about 12 m of rise to 1.6 km (approximately 30 minutes of arc).

MAGNETIC MEASUREMENTS

The direction and intensity of remanent magnetization was measured in a 5-cps fluxgate spinner magnetometer of the type

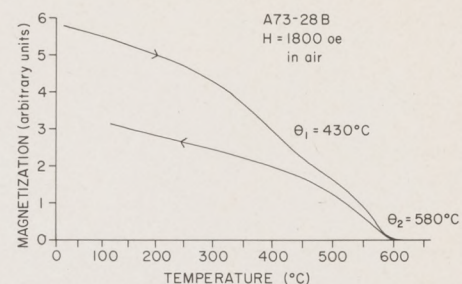


Figure 4. Thermomagnetic curve for specimen of red clay. Θ_1 and Θ_2 are Curie temperatures of different magnetic phases.

described by Foster (1966). Alternating field (a.f.) demagnetization was carried out on selected samples with equipment of the type described by McElhinny (1966). Resulting curves of five specimens along with the concomitant change of direction are shown in Figure 1. It can be seen that the sediment types used in this study possess a broad range of stabilities. However, in most of the cases shown, the median destructive field is above 100 oe, indicating that a component of considerable stability is present in the rock. The geometric mean value for the natural remanent magnetization (NRM) is 7.8×10^{-6} emu/g, ranging from 4×10^{-7} emu/g to 8×10^{-5} emu/g (Fig. 2). The fact that a range of stabilities and intensities are represented is not surprising considering the variety of lithologies used in this study. The average intensity of magnetization after demagnetization in 150 oe is 3.3×10^{-6} emu/g, which indicates that the average median destructive field is between 100 and 150 oe. This denotes relatively good stability. The susceptibility k was measured on a commercially available susceptibility bridge. The geometric mean value for k was 3.5×10^{-5} emu/g, which is higher than the

TABLE 1. FAUNAL LIST—SELECTED SITES IN THE SAN PEDRO VALLEY, ARIZONA

Taxa	Post Ranch	Merdevill Ranch	Bonanza	Honey's Hummock	McRae Wash	Horse green bed	Wolf Ranch	Cal Tech	Calif. Wash	Johnson Pocket	Gidley level	Glyptotherium	Prospect
<i>Sorex</i> sp. (shrew)							X		X				
Talpidae (mole)													
<i>Simonycteris stooki</i> (bat)							X	X					
<i>Eptesicus</i> sp. (brown bat)													
<i>Glyptotherium arizonae</i> (glyptothere)												X	X
Leporidae (rabbit)		X											
<i>Notolagus</i> sp. (rabbit)							X						
<i>Aluralagus</i> sp. (rabbit)		X	X										
<i>Sylvilagus</i> sp. (rabbit)									X			X	
<i>Nekrolagus</i> sp. (rabbit)							X						
<i>Lepus</i> sp. (rabbit)												X	
<i>Spermophilus bensoni</i> (squirrel)		X				X	X		X				
<i>Spermophilus cohi</i> (squirrel)												X	X
<i>Castor</i> sp. (beaver)												X	X
<i>Geomys minor</i> (gopher)		X	X						X				
<i>Geomys pereimilis</i> (gopher)							X		X			X	X
<i>Cratogeomys bensoni</i> (gopher)		X	X										
<i>Perognathus</i> sp. (pocket mouse)		X	X		X		X		X			X	
<i>Protopodomyia minor</i> (kangaroo rat)		X	X		X		X						
<i>Protopodomyia idahoensis</i> (kangaroo rat)							X		X				
<i>Dipodomys gidleyi</i> (kangaroo rat)												X	X
<i>Bensonius arizonae</i> (small mouse)		X	X			X	X		X				
<i>Peromyscus</i> sp. (deer mouse)							X					X	X
<i>Batomys minimus</i> (pigmy mouse)		X	X			X	X						
<i>Batomys brachygnathus</i> (pigmy mouse)							X					X	
<i>Onychomys bensoni</i> (grasshopper mouse)			X				X						
<i>Onychomys pedroensis</i> (grasshopper mouse)												X	
<i>Stigmodon medius</i> (cotton rat)		X	X		X	X	X						
<i>Stigmodon minor</i> (cotton rat)								X		X	X		
<i>Stigmodon martini</i> (cotton rat)							X		X	X	X		
<i>Neotoma fossilis</i> (pack rat)		X	X										
<i>Neotoma</i> sp. (pack rat)					X	X	X					X	
<i>Synaptomys</i> (Metazomys) sp. (lemming)									X				
<i>Plithenacomys</i> sp. (pine vole)		X											
<i>Ondatra idahoensis</i> (muskrat)									X				
<i>Coendou</i> sp. (tree porcupine)							X			X			
<i>Neocherus</i> sp. (capybara)								X					
<i>Canis edwardsii</i> (coyote)												X	
<i>Canis</i> sp. (dog)			X							X			
cf. <i>Borophagus</i> sp. (dog)		X											
<i>Spilogale pedroensis</i> (spotted skunk)												X	
Mustelidae (weasel)		X										X	
<i>Felis</i> sp. (cat)		X											
<i>Panthera</i> sp. (jaguar)												X	
cf. <i>Stegomastodon</i> sp. (gomphothere)								X				X	
cf. <i>Cuvierontus</i> sp. (gomphothere)		X	X				X		X				
<i>Nannippus</i> cf. <i>phlegon</i> (three-toed horse)		X	X	X	X	X	X						
<i>Equus</i> sp. (horse)		X	X	X	X	X	X	X	X	X	X	X	X
<i>Platygomys</i> sp. (peccary)		X	X		X					X	X		
<i>Tamandua</i> sp. (llama)			X									X	X
<i>Camelops</i> sp. (camel)		X	X			X	X	X	X	X	X		
<i>Odocoileus</i> sp. (deer)					X		X						
<i>Capromeryx gidleyi</i> (pronghorn)												X	
Antilocapridae (pronghorn)		X	X		X								

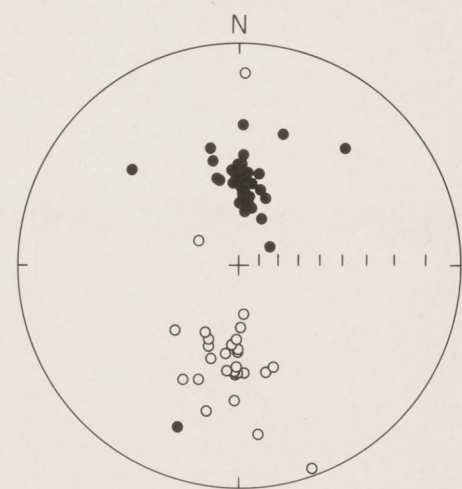


Figure 5. Site mean directions of magnetization for 57 Curtis Ranch sites after alternating field demagnetization plotted on stereographic projection. Filled circles from normally magnetized sites (lower hemisphere projections), open circles from reversely magnetized sites.

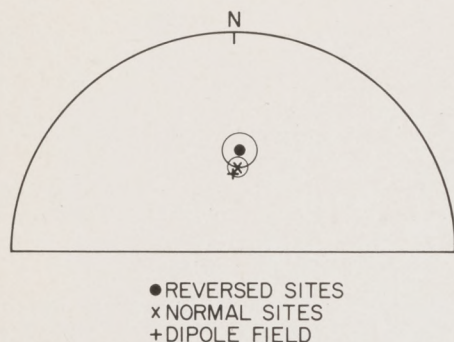


Figure 6. Mean directions of normally and reversely magnetized sites from Curtis Ranch with circles of 95 percent confidence plotted on lower hemisphere of stereographic projection.

mean intensity of magnetization. In Figure 1, the a.f. demagnetization curves shown represent sediment samples with the following lithologies: calcareous red claystone (C and D), greenish silty clay (B and E), and brown silty clay (A). Blanket demagnetization was performed on all sites in peak fields of 150 oe. This field intensity was found to be sufficient to remove most low-coercivity viscous components, which are present in almost all of the samples. This led to good groupings within most of the sites. However, some sites possessed a more stable secondary component, which required treatment in higher fields. These sites often possessed strung distributions between the present normal field and past reversed directions of the Earth's field (Sample D, Fig. 1). Although the mean directions from these sites clearly are not an adequate measure of the magnetic field at the time of deposition, usually the correct polarity of the original field is not in doubt, so that useful information is obtained from these sites even if a significant secondary component remains after a.f. demagnetization. At some other sites, particularly those that are initially weakly magnetized, the cleaning field should be less than 150 oe. However, to determine the ideal washing field for each site would require a.f. demagnetization curves on each site. This is impractical in studies such as the present one, in which the primary purpose of the study is to determine magnetic polarity.

Thermal demagnetization studies were also performed on six pilot specimens representing various lithologies (Fig. 3) to determine whether thermal demagnetization is more effective than a.f. demagnetization. No significant changes in direction occurred within these specimens up to the Curie temperature of magnetite. Because a.f. demagnetization proved to be the more efficient method of removing unwanted secondary components, this was the technique employed routinely on all sites.

To understand better the means by which these sediments become magnetized, it is necessary to identify the mineral responsi-

ble for the NRM. To do this a magnetic separate was prepared using the method described in Løvlie and others (1971). Strong field thermomagnetic curves were obtained for separates from five representative sites in the Curtis Ranch section. All heating and cooling was performed in air. The instrument employed is a vertical motion instrument utilizing an electrobalance to measure the change in magnetic intensity. The change in magnetic moment against temperature is continuously recorded on an X/Y plotter. The saturating field is produced by a 4-in. electromagnet.

The thermomagnetic curves are irreversible and are similar for all sites. A representative curve is shown in Figure 4. The magnetic material contained two magnetic phases, one with a Curie temperature of about 400°C and the second (magnetite) with a Curie temperature of 580°C. The phase with the Curie temperature at 400°C cannot be identified with certainty but is probably a titanomagnetite or titanomaghemite. This magnetic phase may be responsible for the consistent drop in

magnetic intensity at 400°C noted during the thermal demagnetization experiments (Fig. 3). Because the principal magnetic mineral within these sediment samples is clearly magnetite and the layers are not substantially weathered, their remanence is most likely detrital remanent magnetization. It is therefore most probable that the remanence dates from the time of the deposition of the sediment. The particles of detrital magnetite are most likely derived from the mountains proximal to the San Pedro basin.

Figure 5 shows the site mean directions of magnetization for 57 Curtis Ranch sites where the best estimate of the precision is greater than 10 (Fisher, 1953). The site mean direction for the normally magnetized sites is declination 3.3°, inclination +48.1°; and for the reversely magnetized sites, it is declination 186.4°, inclination -39.6°. The circles of 95 percent confidence (Fisher, 1953) for the normally and reversely magnetized sites are 5.1° and 7.0°, respectively. Figure 6 shows that there is no significant difference between the normal and reversed

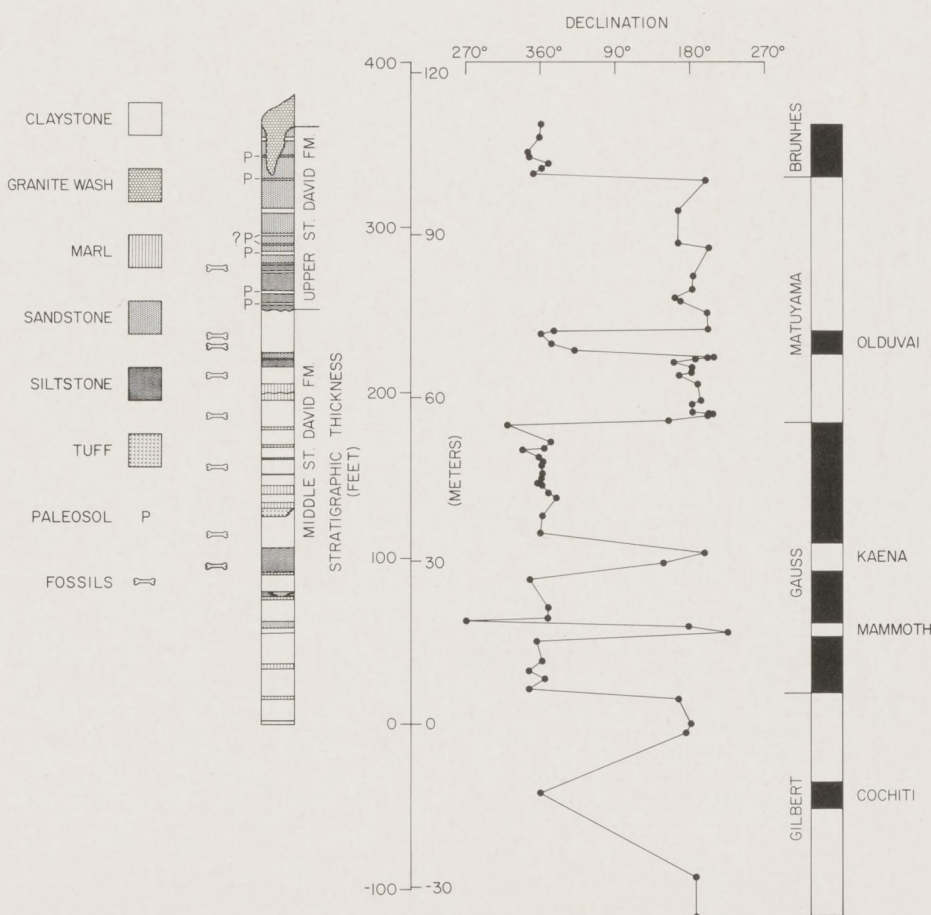


Figure 7. Variation of magnetic declination with stratigraphic level at Curtis Ranch. In magnetic time-scale column, black sections are normally magnetized and white are reversely magnetized. Eight fossil levels named in order of increasing age: Prospect, Glyptotherium (of Gidley), Gidley level, Johnson Pocket, Cal Tech, Horsey green bed, Honey's Hummock, and Bonanza.

sites. The circle of 95 percent confidence from the normally magnetized sites includes the dipole field at the sites. The dipole field does, however, fall outside the circle of confidence of the reversely magnetized sites. This may be due to incomplete removal of secondary components of magnetization in the direction of the Earth's present field. The fact that the mean normal and reversed directions are antiparallel leads us to believe that the sedimentary deposits are accurately recording the changes of the Earth's magnetic field.

MAGNETIC POLARITY ZONES WITHIN THE ST. DAVID FORMATION

The variation of magnetic declination with stratigraphic level at Curtis Ranch is shown in Figure 7. It can be seen that the Granite Wash unit and the uppermost St. David Formation are normally magnetized, and below this level 11 complete magnetic transitions are recorded. Our interpretation of these magnetic polarity zones in terms of the time scale of Cox and others (1964) is given on the right-hand side of the diagram. We believe that the section spans the time from the upper Gilbert Epoch into the Brunhes Epoch. The mammal-bearing sequence ranges from the upper Gauss Epoch to the lower Matuyama Epoch, which places it, in terms of marine stratigraphy at least, within upper Pliocene and lowest Pleistocene time. This time interval includes at least a part of the Blancan Land Mammal Age (Savage and Curtis, 1970). The lower part of the reversed magnetic polarity zone associated with the middle and upper member of the St. David Formation can be correlated to a reversely magnetized volcanic ash. This ash, which is within the middle member of the St. David Formation,

has been dated by Scarborough (1974) at 2.5 ± 0.4 m.y.¹ This radiometric age determination favors the correlation of the associated reversed-polarity zone with the Matuyama Epoch (0.7 to 2.4 m.y.) rather than the Gilbert Epoch (3.3 to 5.1 m.y.).

If our identification of the magnetic polarity zones is correct, the 11 magnetic reversals recorded at Curtis Ranch represent time planes of known absolute age (Dalrymple, 1972). The most uncertain time plane in this regard is the uppermost one, which is most likely the base of the Brunhes event. Because of the abundant conglomerate and paleosol deposits in this interval, our sampling density was not close enough to resolve events as short as the Jaramillo Epoch. Therefore, it seems most probable that the indicated transition is the Brunhes-Matuyama boundary and that the Jaramillo event is missing in this stratigraphic section (Fig. 7). The location of these absolute time planes within the section also provides a means to date the entire section. That is, the age of any stratigraphic horizon in the section may be reasonably estimated by an interpolation between the time planes that bound it. This assumes that the sedimentation of the St. David Formation, although decidedly episodic in character, sampled the Earth's magnetic field with sufficient time frequency to accurately record its history of polarity changes. By this reasoning, then, we can say that the fossiliferous strata in the Curtis Ranch section

(Fig. 7) extend discontinuously over a 1-m.y. period, from just above the Kaena event (~ 2.7 m.y.) to just above the Olduvai event (~ 1.7 m.y.).

The vertical succession of magnetic polarity zones at Curtis Ranch is repeated also on the opposite side of the San Pedro Valley, as shown in Figure 8. In fact these same magnetic polarity zones may be traced in plan view over a 64-km reach of the San Pedro Valley (Fig. 9), in a manner reminiscent of the "magnetic stripes" of the sea floor. Our best estimate of the elevation of the principal magnetic transitions along this length of the San Pedro Valley is shown in Figure 10. If our interpretation of the magnetic polarity stratigraphy is correct, then Figure 10 depicts the absolute chronostratigraphic zonation of the St. David Formation. It may be used, therefore, to infer the absolute ages for various stratigraphic intervals and fossil sites along this stretch of the San Pedro Valley.

STRATIGRAPHIC PALEONTOLOGY

Figure 11 shows the superposition of 13 selected fossil sites within the upper San Pedro Valley. These sites are ordered according to their observed lithostratigraphic and magnetic-stratigraphic position. Absolute ages of the sites can be interpolated from our magnetic-stratigraphic column (Fig. 11), using the age assignments of Opdyke (1972).

We recognize four important temporal datum planes in the fossil sequence of the San Pedro Valley. These datum planes specify the time at which minor but significant changes occurred in the total vertebrate fossil record. They are similar in concept to the datum planes used in Cenozoic planktonic and foraminiferal zonation (Hornibrook and Edwards, 1971),

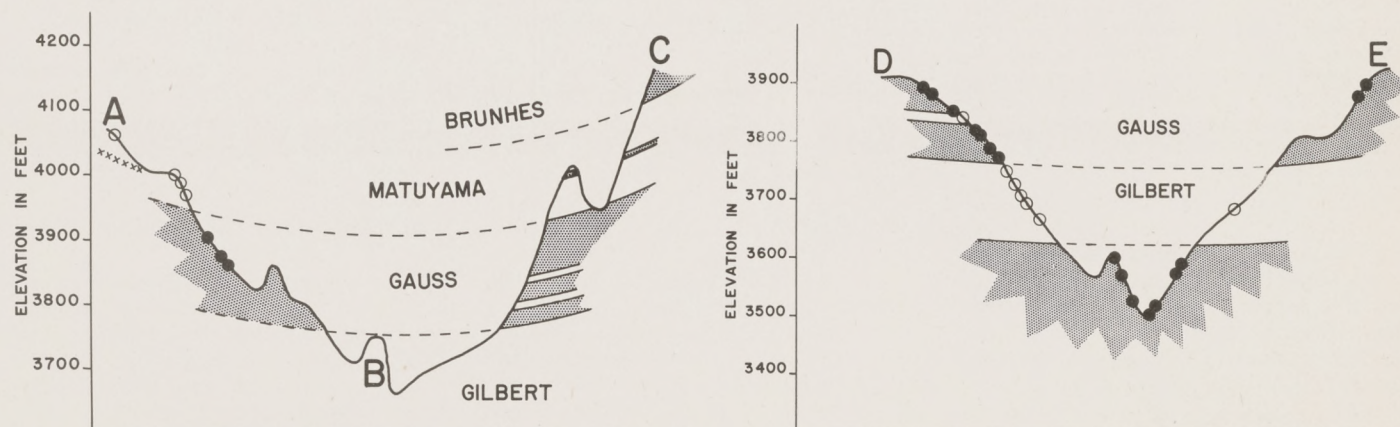


Figure 8. Magnetic polarity zonation and topographic profiles across San Pedro Valley. Shaded areas (black dots) show normally magnetized strata; clear areas (open circles) show reversely magnetized strata. A. Transect ABC located on Figure 9. Segment BC represents Curtis Ranch section (Fig. 7) including 81 sites, which are not shown. Segment AB includes California Wash faunal site, located just above Matuyama-Gauss boundary and below volcanic ash zone whose stratigraphic position is indicated by checkered pattern. This ash has been dated at 2.5 ± 0.4 m.y. (Scarborough, 1974). B. Transect DE located in Figure 9. Includes Mendelev Ranch faunal site, which is located just above Gilbert-Gauss boundary near point D.

¹ RS-35a-68 of the University of Arizona Laboratory of Isotope Geochemistry. The sample is a pure, crystal-poor, air-fall vitric ash, brown, 35 cm thick. Glass shards were dated. Analytical data: K = 2.55 percent, $Ar^{40}_{rad} = 12.0 \times 10^{-12}$ m/g, atmospheric Ar = 90 percent. A different ash bed immediately underlying the Post Ranch faunal horizon (see Fig. 11) has also been dated at 3.1 ± 0.7 m.y. by the fission-track method on zircon (R.A.K. Tahirkheli, 1974, personal commun.).



Figure 9. Plan view of magnetic polarity zones observed in St. David Formation of upper San Pedro Valley. Area of exposed St. David Formation lies generally downslope from Whetstone scarp of San Pedro River and is outlined approximately by dashed line. Patterned areas (black dots), normally magnetized strata; clear areas (open circles), reversely magnetized strata. Magnetic polarity zone distribution based on 160 sample sites, 81 of which lie along line segment BC, Curtis Ranch section (Fig. 7). Locations F, G, and H indicate positions of Post Ranch, McRae Wash, and Wolf Ranch fossil localities, respectively.

but they are more restricted in geographic range, being limited to the San Pedro Valley. Our datum planes have only two dimensions; they have no duration and are therefore distinct from biostratigraphic zones.

Datum Plane I

***Sigmodon medius* Appearance (3.1 m.y.).** This datum marks the first appearance of

Sigmodon medius in the San Pedro Valley. *Sigmodon* is not found in deposits older than Blancan Land Mammal Age. Other early Blancan faunas that contain *Sigmodon* are the 111 Ranch fauna of Arizona, the Rexroad and Deer Park faunas of Kansas, and the Sand Draw fauna of Nebraska.

Several other taxa that occur for the first time in the San Pedro Valley deposits at the *Sigmodon medius* datum are *Aluralagus* sp., *Bensonmys arizonae*, *Baiomys minimus*, *Onychomys bensoni*, *Neotoma fossilis*, *Spermophilus bensoni*, and *Pliophenacomys* sp.

Datum Plane II

***Nannippus* Disappearance (2.4 m.y.).** The three-toed horse, *Nannippus phlegon*, occurs in many Blancan faunas of Arizona and elsewhere in North America. This datum marks the latest known occurrence of *Nannippus phlegon* in the San Pedro Valley. Probably the latest known occurrence of *Nannippus* is *N. phlegon* of the Blanco fauna, Texas.

Other taxa that are absent in the San Pedro Valley above the *Nannippus* (extinction) datum are *Aluralagus* sp., *Pliophenacomys* sp., and *Onychomys bensoni*. Mammals that appear in the San Pedro Valley at this datum are *Nekrolagus* sp., *Geomys persimilis*, *Baiomys brachygnathus*, *Sigmodon curtisi*, and *Coendou* sp.

Datum Plane III

***Ondatra idahoensis* Appearance (2.1 m.y.).** This datum marks the earliest record of the ancestral muskrat, *Ondatra idahoensis*, in the San Pedro Valley. Other early records of *Ondatra* are *Ondatra idahoensis* of the Grand View fauna in Idaho, and *Ondatra* cf. *idahoensis* of the Borchers fauna in Kansas.

Glyptotherium arizonae, *Sylvilagus* sp., *Sigmodon minor*, and *Synaptomys* (*Metaxomys*) sp. also appear in the San Pedro Valley deposits at the *Ondatra idahoensis* datum. *Nekrolagus* sp. and *Sigmodon medius* are not known in the San Pedro Valley above this datum.

Datum Plane IV

***Lepus* sp. Appearance (1.9 m.y.).** The earliest record of the rabbit, *Lepus* sp., in the San Pedro Valley occurs at this datum. Other early occurrences of *Lepus* are *Lepus* cf. *californicus* of the Borchers fauna, Kansas, and *Lepus* sp. of the Vallecito Creek fauna, California.

Other mammal taxa that appear in the San Pedro Valley deposits at the *Lepus* datum are *Spermophilus cochisei*, *Castor*

sp., and *Dipodomys gidleyi*. The genera *Prodipodomys*, *Bensonmys*, *Synaptomys* (*Metaxomys*), and *Stegomastodon* are not recorded above this datum in the San Pedro Valley.

The *Lepus* sp. datum plane is a particularly useful and important datum for two reasons. First of all, this datum marks the appearance of a form regarded as definitive for early Irvingtonian Land Mammal Age (Hibbard and others, 1965; Downs and White, 1968). Therefore, the *Lepus* datum in the San Pedro Valley must be close to the Blancan-Irvingtonian boundary according to this definition. (In large mamal associations, Savage [1951] used the appearance of *Mammuthus* to mark the base of the Irvingtonian. These alternate concepts of the basal Irvingtonian do not necessarily refer to the same point in time.) Secondly, it is close in time to the Olduvai event, within which the Pliocene-Pleistocene boundary occurs (Berggren and others, 1967). Therefore, with the *Lepus* datum at or just below the Pliocene-Pleistocene boundary, Irvingtonian faunas can be regarded essentially as Pleistocene and Blancan faunas as Pliocene. It is noteworthy, however, that this definition of the Pliocene-Pleistocene boundary (for example, Berggren and others, 1967) does not preclude substantial terrestrial climate changes during late Pliocene time.

A number of the small mammals in the San Pedro Valley stratigraphic sequence have apparently evolved in place. The following taxa are believed to reflect ancestral-descendant relations: *Geomys minor* → *Geomys persimilis*, *Prodipodomys idahoensis* → *Dipodomys gidleyi*, *Baiomys minimus* → *Baiomys brachygnathus*, *Onychomys bensoni* → *Onychomys pedroensis*, *Sigmodon medius* → *Sigmodon minor*. A study of the rates of evolution for these taxa is beyond the scope of this paper, but the excellent time-stratigraphic control will enable such a study.

The faunal datum planes as defined above are interpolated from present magnetic evidence for the San Pedro Valley and must be updated as new information becomes available.

SUMMARY AND DISCUSSION

The study presented here demonstrates that, under some circumstances at least, meaningful measurements of depositional remanence may be obtained from Neogene terrestrial sediments and that accurate chronostratigraphic horizons and magnetic polarity transitions may be localized. However, it must be pointed out that not every outcrop of terrestrial rock is amenable to an analysis as useful as that given here. The

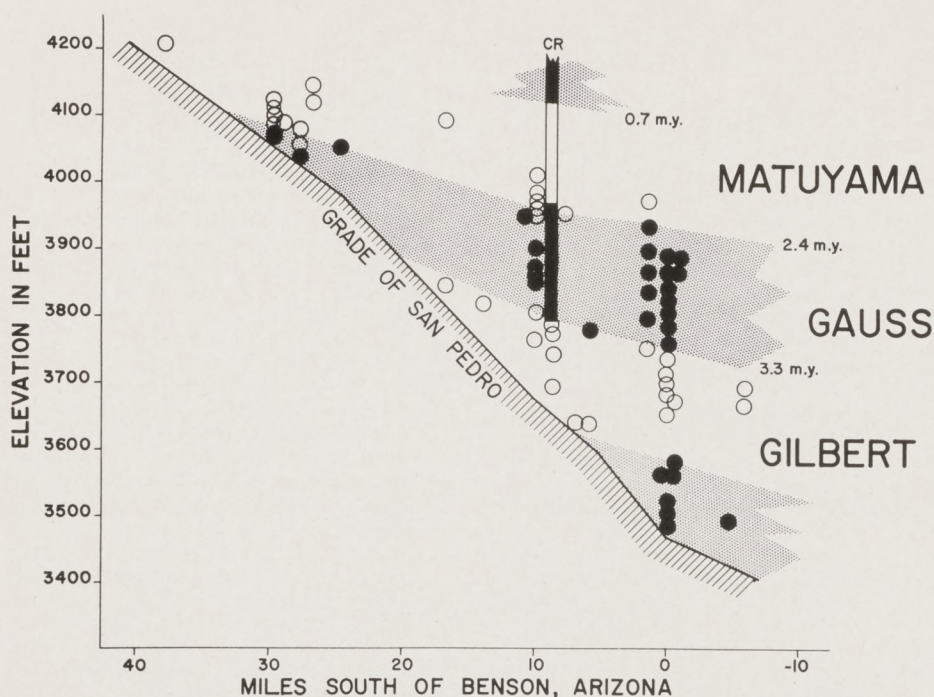


Figure 10. Vertical distribution of magnetic polarity zones within St. David Formation along upper San Pedro Valley. Shaded areas (black dots), normally magnetized strata; clear areas (open circles), reversely magnetized strata. Data base is same as described in Figure 9. Continuum of Curtis Ranch data (81 data points) represented by bar labeled CR.

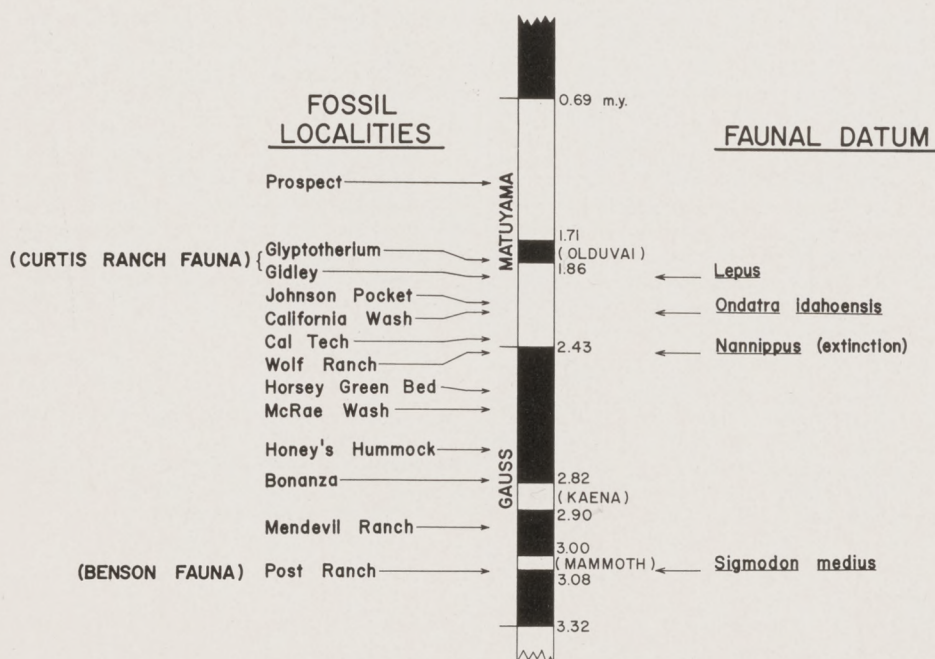


Figure 11. Temporal relations of fossil-mammal localities in upper San Pedro Valley with respect to magnetic time scale. Fossil localities include all eight of those in Curtis Ranch section (see Fig. 7) as well as five others whose position on the magnetic time scale has been directly determined (California Wash, Wolf Ranch, McRae Wash, Mendevill Ranch, and Post Ranch). Magnetic polarity zonation portrayed is that actually observed in Curtis Ranch section (Fig. 7) along with our time-scale interpretation.

Curtis Ranch section was especially favorable because of its lithology, fossil content, and long continuous depositional record.

An important limitation to the method is imposed by the quality and continuity of sediment present in a given outcrop. Fine-grained sediment, such as claystone and siltstone is the preferred lithology for reliable paleomagnetic studies. A lengthy stratigraphic column also enhances the prospects of crossing one or more magnetic transitions. At present only magnetic epochs and events from the past 5 m.y. have reliably dated boundaries.

Our experience (in addition to the San Pedro Valley, this also includes data from Meade County, Kansas; the Texas Panhandle, and the Anza-Borrego region, California) suggests that an isolated, fossiliferous outcrop can be quite easily assigned to the correct magnetic epoch, for example, Brunhes, Matuyama, and so forth, on the basis of one or two accurate magnetic polarity determinations, plus some knowledge of the associated fossils. This is explained by the fact that during the past 5.1 m.y., only 15 percent of the time is marked by magnetic polarities other than that of the principal epoch (Opdyke, 1972). That is, on a random basis, 85 percent of the time during the past 5.1 m.y. has been occupied with the major "epochs" rather than the smaller "events" within the epochs. For example, the chance of finding on a random basis a normal (+) polarity (the Jaramillo or Olduvai events) within sediments of Matuyama age are only one in eight. A Matuyama-age fossil, then, will most likely be buried in a reversely (-) magnetized rock.

Once the correct magnetic epoch has been designated for a given sediment, its age has been circumscribed on a rather broad scale. Time resolution beyond the simple designation of Epoch requires a much more extensive and intensive sampling program. At Curtis Ranch for example we found that a sampling frequency of 0.5 to 1.5 percent (2 to 3 cm every 2 to 3 m or so) was needed to find and define the pertinent magnetic events. This density of sampling may be precluded in many outcrops by an abbreviated or incomplete stratigraphic section or the absence of suitable material. A judicious selection of outcrop is thus necessary to exploit the potential of magnetic polarity stratigraphy.

The real power of magnetic polarity stratigraphy, that is, its potential for absolute time correlation on a world-wide scale, is exemplified by the faunal datum planes we have erected for the San Pedro Valley. These faunal datum planes may prove useful for comparisons and correlations with other vertebrate fossil localities. In like fashion, these faunal datum planes may be

Gauss = Pleistocene to Pliocene (Blancan)
Matuyama = Pleistocene to Pliocene (early) (Blancan / Brunhes)

related directly to the faunal datum planes compiled from the marine record (Berggren, 1972). A comprehensive chronology within this time span may thus be obtained, based on magnetic criteria.

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The Paleomagnetism and Magnetic Polarity Stratigraphy of the Mammal-Bearing Section of Anza Borrego State Park, California

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We sampled 150 sites in fine-grained Plio-Pleistocene sediments of the Palm Springs and Imperial Formations. Sampling was confined to 3000 m of stratigraphically continuous section containing abundant vertebrate fossil remains of the Vallecito Creek, Arroyo Seco, and Layer Cake local faunas of the Irvingtonian and Blancan Land Mammal Ages. The magnetic stability of these sediments was sufficient to delineate the magnetic stratigraphy, which ranges from below the Cochiti event at the base, to the Matuyama reversed magnetic epoch at the top of the section. Eight faunal events are placed relative to the magnetic polarity sequence. They are cf. *Plihippus* extinction, *Geomys* appearance, cf. *Equus* appearance, *Tremarctos* appearance, *Hypolagus* extinction, cf. *Odocoileus* appearance, *Smilodon* and ? *Euceratherium* appearance. The latter two faunal events characterize Irvingtonian Land Mammal Age. The transition from the Blancan to Irvingtonian Land Mammal Age occurs in the lower Matuyama magnetic epoch close to the Pliocene-Pleistocene boundary. The appearance of European migrants during the lower Matuyama magnetic epoch indicates that the Bering land bridge was exposed for animal migration between Europe and North America at this time.

INTRODUCTION

A thick section (4600 m) of poorly indurated Plio-Pleistocene sands, muds, silts, and clays are exposed in homoclinally dipping beds within the Anza Borrego State Park, California (Fig. 1). These beds are richly fossiliferous, containing vertebrate fossils that have Blancan and Irvingtonian affinities. The purposes of this study are to correlate these fossils with the known magnetic time scale and with the previously

studied vertebrate fossil localities in the San Pedro Valley of Southern Arizona. These detailed biostratigraphic data may help to elucidate the faunal change from Blancan to Irvingtonian Land Mammal Ages.

GEOLOGIC SETTING

The section chosen for study includes the entire Palm Springs Formation (Woodring, 1932), which averages 3000 m in thickness and is composed predominantly of

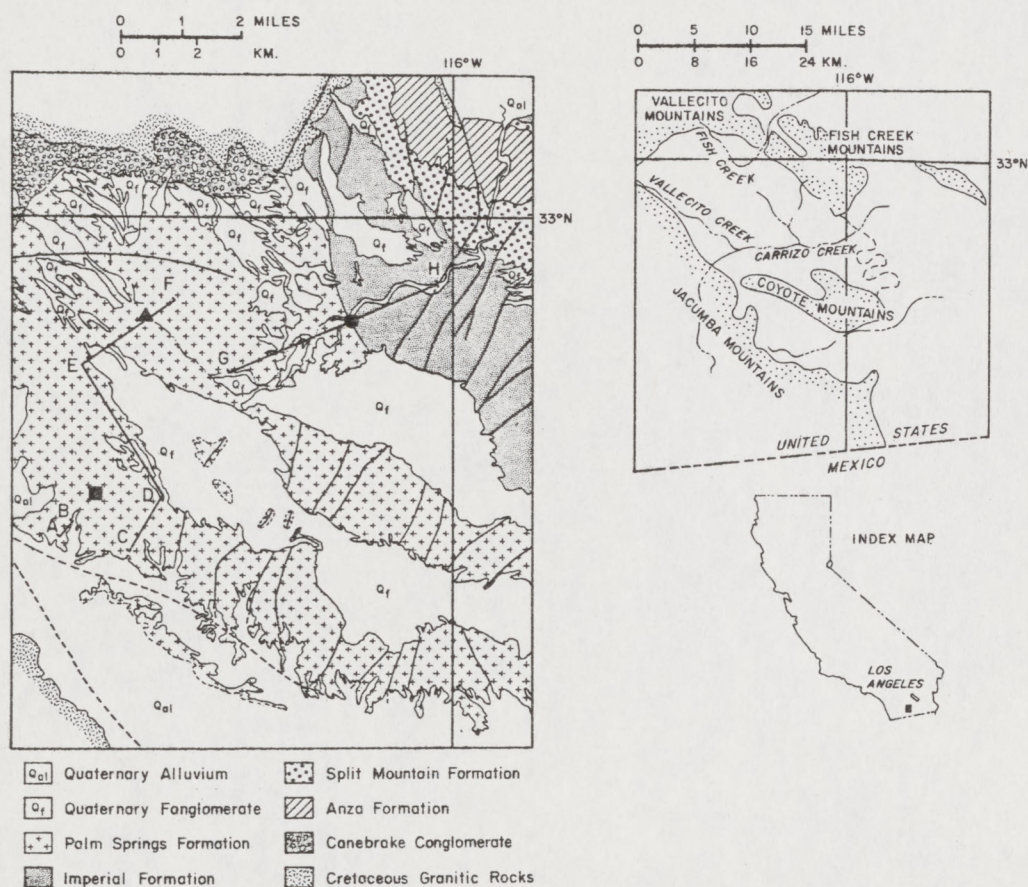


FIG. 1. Geological map of the region under study adapted from Woodard (1974) indicating schematically the sampled sections. The three large filled symbols denote the locations of three faunal zones of Downs and White (1968): Zone 7 (circle) occurs at the contact of the Palm Springs and Imperial Formations at the corner of sections 3, 4, 9, and 10, T. 14S, R. 8E. Zone 29 (triangle) intersects vertebrate locality 1711, which is located adjacent to Fish Creek in the NE 1/4 of section 12, T. 14S, R. 7E. Zone 56 (square) intersects a prominent topographic ridge at the "view of Badlands" in the east half of section 23, T. 14S, R. 7E.

terrestrial sediments in a sequence of interbedded sandstone, claystone, arkosic sandstone, pebble conglomerate, and occasional freshwater marl. Littoral marine environments are indicated by the presence of an impoverished marine invertebrate fauna which occurs sporadically in the lower part of the formation (Downs and Woodard, 1961; Woodard, 1974). The presence of detrital foraminifera of Cretaceous age (Merriam and Bandy, 1965) indicates that the sediments of the Palm Springs Formation were being supplied partly by the ancestral Colorado River, along with locally derived coarse detritus from the rising

Peninsular Range along the western margin of the basin. Our sampled section included only the upper part of the Imperial Formation which has yielded the earliest vertebrate fossils known from the region. The Imperial Formation (Tarbet, 1951) contains a middle member of conspicuously rhythmically bedded gray silty mudstone and very fine quartz sand. The upper part of the Imperial Formation consists of alternating siltstone and sandstone with intercalated biostromal limestones and calc-arenite beds (Woodard, 1974).

Our magnetic polarity section (Figs. 1 and 7) is tied into the faunal zones of Downs

and White (1968) for biostratigraphic and geographic control. Baselines for the faunal zones of Downs and White are zones 29 and 56. Zone 29 is located at the Gauss-Gilbert boundary (2255 m) in our section. Zone 56 crosses Arroyo Huevo (NE ¼ sect. 25, T. 14 S, R. 7E) at 450 m in our section. Another reference point is the contact of the Palm Springs and Imperial Formations (Downs and White zone 7), at 3600 m in our section.

SAMPLING

We sampled 150 sites during 3 visits to the area in 1973 and 1974. Three samples were collected per site using the methods and techniques described by Johnson and others (1975). The sites were located on aerial photographs and the stratigraphic position and total thickness were calculated from the aerial photographs.

MAGNETIC ANALYSIS

The samples were cut into 2.5 cm cubes and measured on a high-sensitivity slow-speed Digico magnetometer, as described by Molyneux (1971). Alternating field demagnetization curves were done on 31 samples from sites spread throughout the sampled section. Alternating field demagnetization was carried out in steps in peak fields of up to 500 Oe using apparatus and techniques similar to those described by McElhinny (1966). Figure 2 illustrates the behavior of eight representative samples, four of whose NRM directions are toward the north with positive inclinations and four which are directed toward the south with both positive and negative inclinations. All four of these latter samples were, however, probably originally magnetized in a reversed field. It can be seen for three of the four reversely magnetized samples that stable end points were not achieved until peak fields on the order of 300 Oe were applied. In the case of one sample (101B) a negative inclination was not reached even in peak fields as high as

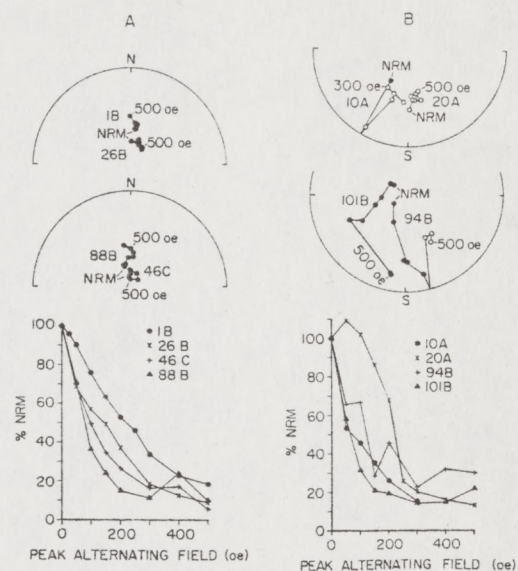


FIG. 2. Alternating field demagnetization curves and changes of directions on demagnetization of (a) four normally and (b) four reversely magnetized samples from the Anza Borrego section.

500 Oe. Because a secondary vector of considerable stability is present, therefore, all sites were routinely demagnetized in peak fields of 300 Oe. After the demagnetization step, all sites were measured and the mean directions of magnetization were determined. Figure 3 shows the mean site directions of magnetization of all sites that are not statistically random before and after a.f. demagnetization in peak fields of 300 Oe. The mean directions of magnetization after demagnetization may be classified into three groups. One category of sites are northerly directed with positive inclinations which are not significantly different from the earth's dipole field. A second category are sites which yield southerly directions with negative and some positive inclinations which are not grouped close to the earth's dipole field. A smaller set of samples exhibit westerly declinations and mostly positive inclinations. This latter category is classed as an intermediate direction of magnetization. It is clear that on the whole the reversed directions are essentially a strung distribution toward the present field and are

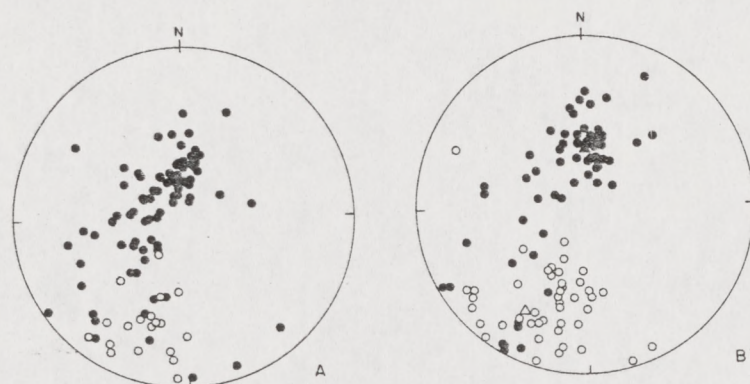


FIG. 3. (a) Site mean directions of NRM for statistically significant sites. (b) Mean site directions for statistically significant sites after a.f. demagnetization of 300 Oe peak field. The plot is a stereographic projection. The filled circles are directions with north-seeking components directed below the horizontal, and the open circles represent inclinations above the horizontal. The mean direction of magnetization for the normally magnetized sites in 3b is represented by the filled triangle and the reversed sites by the open triangle.

most probably a result of a secondary direction of magnetization that remains after a.f. demagnetization in peak fields as high as 300 Oe. The secondary component was clearly acquired after folding of the beds (strike = 300°, dip = 20°SW) in a normally directed field, probably during the Brunhes normal polarity epoch. This would account for the too shallow reversed directions and the strung distribution of the site mean directions toward the west.

MAGNETIC MINERALOGY

The magnetic fractions from six of the sites were obtained using methods and techniques described by Løvlie *et al.* (1971).

TABLE 1
CURIE TEMPERATURE (θ), ISOTHERMAL REMANENT
MAGNETIZATION (J_{IRM}) AND REMANENT
COERCIVITY (H_{cr}) DATA FOR
SELECTED SAMPLES

Site	θ (°C)	J_{IRM} ($\times 10^{-3}$ emu/g)	H_{cr} (Oe)
AB20	633	1.112	308
AB37	558	7.015	322
AB47	563	0.996	564
AB51	598	1.812	245
AB80	560		
AB101	656	0.200	458

The Curie points of the magnetic separates were determined using the Curie point balance described by Kent and Lowrie (1974). The Curie points are given in Table 1 and range from 558 to 656°C. Representative Curie temperature curves are shown in Fig. 4. The Curie temperatures for three of the sites give results indicating that the dominant magnetic mineral is magnetite or titanomagnetite. Three of the sites, however, have Curie temperatures above 600°C, which are higher values than can be expected from the magnetites and titanomagnetites. We believe that the most probable mineral is a stabilized form of maghemite similar to that described by Harrison and Peterson (1965) from deep-sea cores in the Indian Ocean.

Isothermal remanent magnetization (IRM) acquisition curves and remanent coercivities (H_{cr}) were determined for five sites. The values for IRM and H_{cr} are given in Table 1, and the curves from which these values were determined are shown in Fig. 5. In general, the samples acquire 80% or more of the final saturation value in fields as low as 1000 Oe. Some samples do, however, continue to increase in moment up to the maximum fields available (8000 Oe). This asymptotic behavior may be due to a small

fraction of highly coercive material, perhaps haematite. Several samples show pronounced kinks in the back field required to determine the H_{cr} . This is particularly true of sample 47A (Fig. 5). It is clear in this case that a mixture of material with at least two coercivities is present, one of which is much higher than the other. This could be due to a mixture of grain sizes and/or minerals. It would appear that one of the principal results of the magnetic mineralogy study is the great variability of these properties. This is understandable, as at least two provenances are postulated for these sediments, as well as the long time involved in their deposition. It is also true that both marine and nonmarine environments of deposition are present in this sediment sequence.

Studies of viscous remanent magnetization (VRM) were carried out on several sites (Fig. 6), and it is clear that VRM can account for a significant fraction of the natural remanent magnetization (NRM) in certain cases (50% in the sample given).

MAGNETIC STRATIGRAPHY

The data from the preceding section (Fig. 3) show that a significant portion of a secondary component remains after a.f. demagnetization in peak fields of up to 300 Oe. It is possible, however, to unambiguously determine the magnetic polarity in most instances. In Fig. 7 we plot the magnetic

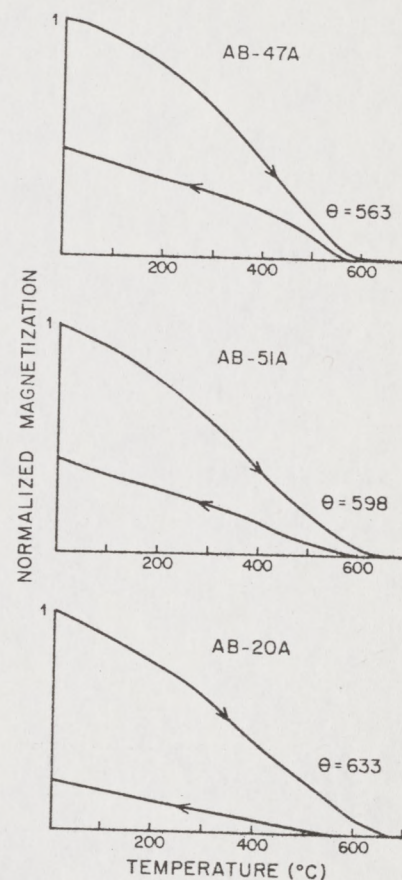


FIG. 4. Curie temperature curves for samples from three different sites.

declination for all sites which have mean directions of magnetization which are statistically significant (Watson, 1956). If only these sites are used, the broad outlines

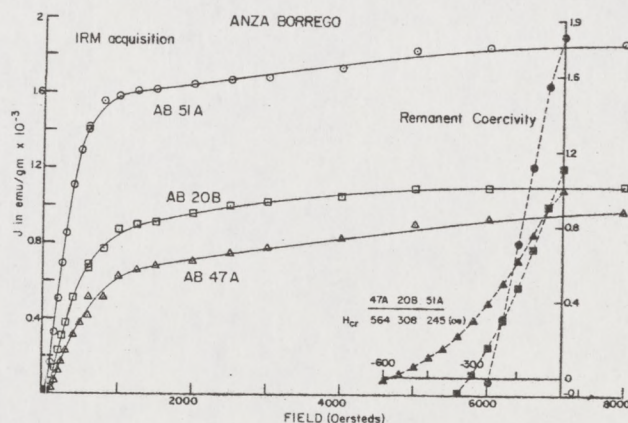


FIG. 5. IRM acquisition curves and remanent coercivity determinations for three samples from Anza Borrego.

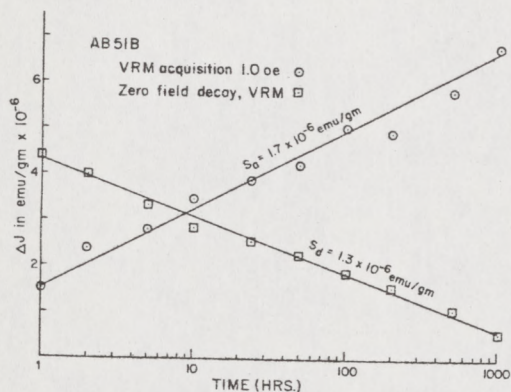


FIG. 6. VRM acquisition and decay curves for normally magnetized sample AB51B from the uppermost part of the section.

of the magnetic stratigraphy are immediately apparent because the site density per unit time is high enough to delineate the polarity structure of the sedimentary column. However, for a full evaluation of the magnetic stratigraphy in Fig. 7, all the information is used in the final interpretation. The sites which are statistically significant are called Class I sites. Class II sites have only two samples per site but the directions are concordant. These cases usually arise when one of the samples from the site has been lost during the sample preparation procedure. In these cases there is no question about the polarity of the sites. Class III sites are those sites which have statistically random directions of magnetization but where two of the three samples are directed in, say, a reversed direction, whereas the third is widely divergent in some intermediate direction. Class IV sites are those which have strung distributions but where the directions change upon a.f. demagnetization in a systematic way so that the polarity information has been obtained. This kind of hierarchy has the advantage of presenting some idea as to the total reliability of the data. The magnetic stratigraphy on the left of the figure is derived from all the magnetic data.

The data yield the following results. The upper three sites representing 27 m

have normal polarity. Below these three sites, 434 m of reversely magnetized sediment is present. A normal magnetozone occurs between 427 and 503 m. Below this occurs 488 m of reversed sediment, which is followed by a thick normal zone of sediment which extends from 991 m to 2248 m. This normal magnetozone is punctuated by two relatively short reversed sections between 1314 and 1379 m and 1494 to 1692 m. A long series of reversed sites occurs below 2248 to 3414 m and a clearly defined normal section extends from 3414 to 3616 m. Below this magnetozone three reversely magnetized sites occur.

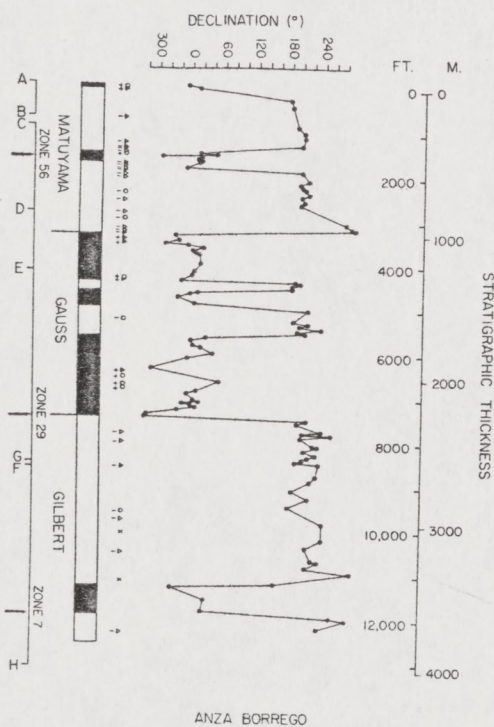


FIG. 7. Magnetic stratigraphy of the Anza Borrego section. Plotted points of the value of the declination are from those sites which give statistically valid mean directions of magnetization (Class I sites). Class II sites, filled triangle; Class III sites, open triangle; Class IV sites, open circle; Class V sites, cross. See text for explanation of classes. Beside each symbol is plotted the interpreted polarity of the site, either (+) normal or (-) reversed. The final interpretation is given on the left side of the figure and is represented by the normal (black) and reversed (white) polarity diagram.

Four sites were sampled below 3800 m, but the sampling density was not great enough to allow the construction of the magnetic stratigraphy beyond this level.

CORRELATION WITH THE REVERSAL TIME SCALE

The question remains as to which part of the reversal time scale this series of reversals of the earth's magnetic field belongs. The only independent means of correlation available at the present time is the vertebrate fauna. The Layer Cake and Arroyo Seco fauna have been placed in the Blancan Mammal Age, while the younger Vallicito Creek fauna has Irvingtonian affinities (Downs and White, 1968). Johnson *et al.* (1975) have shown that the oldest Irvingtonian based on the occurrence of *Lepus* (hare) and other small mammals occurs within the Matuyama reversed polarity epoch in the region of the Olduvai event, whilst the Blancan faunas characterize the Gauss normal polarity epoch and range into the lower Matuyama epoch. It seems certain, therefore that the section under study can be interpreted as Matuyama in the upper 991 m to 2248 m and the upper Gilbert reversed magnetic epoch below 2248 m. This interpretation is given considerable weight by the fact that two reversed events are seen in this section, the Kaena and Mammoth, which is correlative to the Gauss magnetic epoch.

It appears that both boundaries of the Gauss magnetic epoch are present, and therefore we can estimate the age of the normal events which lie above and below the sediments of the Gauss magnetic epoch. A simplistic method of doing this would be to extrapolate the rate of sedimentation from the sediments deposited during the entire Gauss magnetic epoch (140 cm/1000 yr). However, it is clear from the relative position of the two reversed events within the sediments of the Gauss epoch that the sedimentary section in the upper Gauss magnetic epoch is not long enough when compared with sedi-

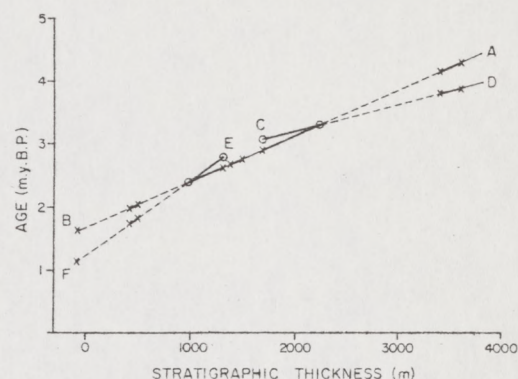


FIG. 8. Plot of rate of sedimentation vs time. Slope AB is the extrapolation for the entire Gauss. Slope CD is the extrapolation upward using the sedimentation rate of the upper Gauss, and EF is an extrapolation downward using the sedimentation rate of the lower Gauss.

ments of the lower Gauss. Therefore a change in the rate of sedimentation occurs at about 3 my. A more meaningful method would be to use the sedimentation rate derived from sediments deposited during upper Gauss time (between the Matuyama/Gauss boundary and the upper reversed, or Kaena, event) for extrapolation into the Matuyama; and to use the sedimentation rate for lower Gauss time sediments deposited between the lower reversed, or Mammoth, event and the Gauss/Gilbert boundary for extrapolation into the Gilbert. The results of both of these analyses are shown in Fig. 8. By using the averaged sedimentation rate during the whole Gauss magnetic epoch, the normal, or Cochiti, event in the Gilbert epoch can be assigned an age older than 4 my (4.16 to 4.31 my). If only the rate for sediments deposited during the lower Gauss magnetic epoch is used, the Cochiti event appears younger than 4 my (3.83 to 3.91 my), which is closer to its age estimated from other studies (3.72 to 3.82 my; Opdyke, 1972). By applying the same rationale, to evaluate the age of the event in the lower Matuyama it can be seen that by extrapolation of the average rate for the total Gauss epoch, the age of this event would be older than 2 my (2.00 to 2.05 my),

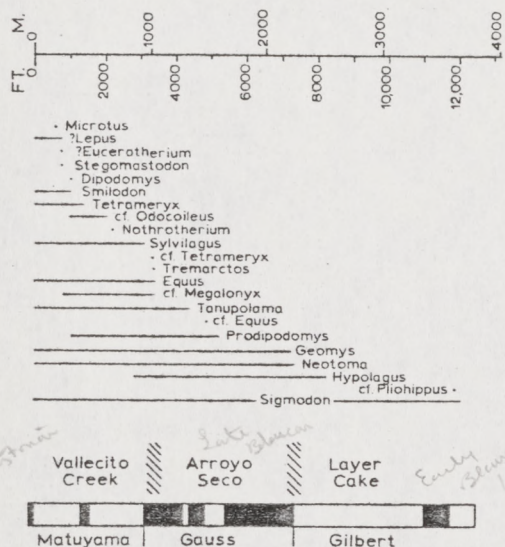


FIG. 9. Stratigraphic range of Anza Borrego faunas plotted against the magnetic stratigraphy.

close to the radiometrically determined age of the Réunion event (2.02 my; MacDougall and Watkins, 1973). However, if the age is determined using only the extrapolation of sedimentary rates from the upper Gauss, the age of the event would be younger than 2 my (1.75 to 1.83 my), which is close to the measured age of the Olduvai event. On the evidence available, the event observed above the Gauss could be either the Olduvai or the Réunion event and the normal polarity zone at the top of the section could be either the basal Jaramillo or Olduvai event, depending on which interpretation is chosen. There are no conclusive means to differentiate between the two interpretations based on magnetic polarity and sedimentation rate.

VERTEBRATE PALEONTOLOGY

A comprehensive faunal list and biostratigraphic division of the mammal fauna from the Anza Borrego State Park was published by Downs and White (1968). Additional fossils have been collected since 1968, and subsequent taxonomic revisions require a reevaluation of the stratigraphic

limits of the fauna. For this study, a check of taxonomic identifications was made by Downs, White, and Zakrzewski. Stratigraphic ranges were checked by Downs and Lindsay. Additions and changes in the faunal list include the addition of the cricetid rodent *Synaptomys* (lemming) (Zakrzewski, 1974); the bat previously identified as *?Myotis* (brown bat) is now identified as a new genus *Anzanycteris* (White, 1969); and *?Mustela* (weasel) is now assigned to the mustelid subfamily *Galictinae*. The faunal division of 1968 is unchanged, although stratigraphic ranges of a few taxa have been extended.

As defined by Downs and White (1968), the Layer Cake fauna is probably early Blancan, the Arroyo Seco fauna is late Blancan, and the Vallecito Creek fauna is early Irvingtonian based on the small mammal fauna. The stratigraphic position with respect to the paleomagnetic transitions of the faunas are shown in Fig. 9. Downs and White (1968) noted that definite boundaries between Layer Cake, Arroyo Seco, and Vallecito Creek faunas could not be delineated. By coincidence, the stratigraphic interval they assigned to the Layer Cake fauna corresponds very closely with the magnetic polarity we assign to the Gilbert magnetic epoch. Similarly, the sediments containing the Arroyo Seco fauna were mostly deposited during the Gauss magnetic epoch, and likewise the Vallecito Creek fauna is found in sediments whose magnetic polarity we assign to the Matuyama magnetic epoch.

The stratigraphic ranges of 20 representative genera within the Anza Borrego sequence are shown in Fig. 9 and discussed below. These genera were selected because of their chronologic significance and their representation in other vertebrate faunas of comparable age. Ranges of other Anza Borrego mammal taxa can be plotted relative to these genera, using the ranges provided in Fig. 2 of Downs and White (1968). The 20 selected genera may be used to define 8 faunal events in the

Anza Borrego stratigraphic sequence. These faunal events, which we name faunal datum planes (Fig. 10), mark the lowest or highest stratigraphic occurrence of a faunal taxon within a continuous stratified sequence correlated to the paleomagnetic time scale. In effect, they correspond to a biostratigraphic boundary, i.e., the limit of a *teilzone*. As used herein, the faunal datum planes are tied to the magnetic polarity sequence in the Anza Borrego deposits. The faunal datum planes established in this paper apply only to the Anza Borrego sequence. The same faunal events may (but do not necessarily have to) occur synchronously in other stratigraphic sequences in North America. Datum planes provide more precise chronologic resolution than previous faunal divisions (Downs and White, 1968; and Tedford, 1970, Fig. 3 and p. 683). In the discussion that follows the lowest stratigraphic occurrence and the highest stratigraphic occurrence are designated LSD and HSD, respectively.

The *cf. Pliohippus* LSD (~3.8 my) marks the highest (and only) stratigraphic occurrence of the horse *Pliohippus* in the Anza Borrego section (*Pliohippus* is considered a Clarendonian and Hemphillian genus). Its record in the Layer Cake fauna indicates the lowest vertebrate fossil level in the Anza Borrego section may be Hemphillian Land Mammal Age. A characteristic Blancan (and younger) genus, the rodent *Sigmodon* (cotton rat), occurs stratigraphically lower than *cf. Pliohippus*.

The *Geomys* LSD (~3.3 my) marks the lowest stratigraphic occurrence of the gopher *Geomys* in the Anza Borrego section. The cricetid rodent *Neotoma* (pack rat) appears in the sequence slightly lower than *Geomys*. Both genera, *Geomys* and *Neotoma*, occur in Blancan and younger faunas in North America.

The *cf. Equus* LSD (~2.9 my) marks the lowest stratigraphic level that yields fossils of the modern horse *Equus* in the Anza

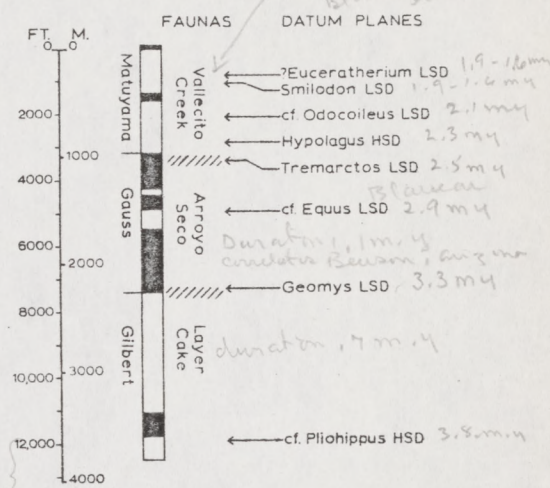


FIG. 10. Vertebrate fossil datum planes from the Anza Borrego section.

Borrego section. *Equus* is also characteristic of Blancan and younger faunas in North America.

The *Tremarctos* LSD (~2.5 my) marks the lowest stratigraphic occurrence of the bear *Tremarctos* in the Anza Borrego section. The rabbit *Sylvilagus*, unquestionable *Equus*, and the pronghorn *cf. Tetrameryx* also appear at the stratigraphic level of the *Tremarctos* LSD. *Tremarctos* is rare in North American faunas; this probably represents its earliest known occurrence in North America.

The *Hypolagus* HSD (~2.3 my) marks the highest stratigraphic occurrence of the rabbit *Hypolagus* in the Anza Borrego section. *Hypolagus* is a common rabbit in Hemphillian and older faunas of North America. It is replaced in Pleistocene and Recent faunas by the cotton tail *Sylvilagus* and the hare *Lepus*.

The *cf. Odocoileus* LSD (~2.1 my) marks the lowest occurrence of a true cervid, e.g., *Odocoileus* or *Cervus*, in the Anza Borrego section. Probably the earliest occurrence of *Odocoileus* in North America is in the Fox Canyon fauna of Kansas. This datum event in the Anza Borrego sequence also approximates the occurrence of the ground sloth *Nothrotherium*, and the

highest occurrence of the stilt-legged camel, cf. *Titanotylopus*, in the sequence.

The *Smilodon* LSD (~1.9 or 1.6 my) marks the lowest occurrence of the well-known saber-toothed cat *Smilodon*, which is known only from Irvingtonian and Rancholabrean faunas in North America. The kangaroo rat *Dipodomys* replaces the ancestral kangaroo rat, *Prodipodomys*, at (approximately) this same stratigraphic level in the Anza Borrego section.

The *?Eucatherium* LSD (~1.9 or 1.6 my) marks the only known occurrence of this bovid in the Anza Borrego section. *Eucatherium*, a Eurasian immigrant, is probably the earliest bovid to inhabit North America. Bovids are not known from Blancan deposits of North America; they are characteristic of Irvingtonian and especially Rancholabrean faunas. The Blancan gomphothere *Stegomastodon* and the hare *Lepus* also occur at this stratigraphic level. The rodent *Microtus* (vole) occurs slightly higher stratigraphically.

The Layer Cake fauna has a duration of about 0.7 my. A single datum event, cf. *Pliohippus* HSD marks the base of this fauna at the base of the Cochiti event in the Gilbert magnetic epoch. The cf. *Pliohippus* HSD should be very near the Hemphillian-Blancan boundary. The Layer Cake fauna correlates approximately with the Fox Canyon fauna of Kansas, based on its magnetic polarity and fauna (Lindsay *et al.*, 1975).

The Arroyo Seco fauna has a duration of about 1.1 my, and is marked by lower (*Geomys*, LSD), middle (*Equus*, LSD), and upper (*Tremarctos*, LSD) faunal datum events. This fauna approximately correlates (through both the fauna and magnetic polarity) with the Benson fauna of southern Arizona, the Red Corral and Cita Canyon faunas of Texas, and the Rexroad, Bender, and Saunders faunas of Kansas (Lindsay *et al.*, 1975).

The Vallecito Creek fauna has a duration of about 0.8 or 1.5 my (depending on the

interpretation of the normal magnetic polarity event in the middle of the Vallecito Creek section), and is marked by four faunal datum events. According to magnetic polarity stratigraphy the *Hypolagus* HSD correlates approximately in time with the Borchers fauna of Kansas. The cf. *Odocoileus* LSD also correlates approximately with time of the Borchers fauna of Kansas, or with that of the Mt. Blanco fauna of Texas. The *Smilodon* and *?Eucatherium* LSD correlate approximately with the Mt. Blanco fauna of Texas or the Curtis Ranch fauna of Arizona (Lindsay *et al.*, 1975). These magnetostratigraphic correlations indicate that most of the Vallecito Creek fauna occurs within Blancan Land Mammal Age, but that it also includes the early part of the Irvingtonian Land Mammal Age.

COMPARISON OF SAN PEDRO VALLEY BEDS WITH ANZA BORREGO

A previous study by Johnson and others (1975) has succeeded in placing the Blancan and Irvingtonian faunas of the San Pedro Valley, Arizona, within the framework of magnetic polarity stratigraphy. It would be instructive, therefore, to more closely compare the faunas of these two areas, since the time spans of the sediments involved are similar. Out of 32 genera, 22 (about 50%) are common to the 2 regions. In the San Pedro Valley the fossil-bearing beds begin about the level of the Mammoth event. At that level *Sigmodon*, *Geomys*, and *Neotoma* are initially recorded. In the Anza Borrego section, however, all three of these species occur earlier in time—*Geomys* and *Neotoma* near the base of the Gauss and *Sigmodon* at the base of the Cochiti event. Clearly a better and more complete record of these animals is present in the Anza Borrego area. Their absence in the lower strata of the San Pedro Valley probably results from a sedimentary regime that did not favor fossil preservation. *Equus* appears in both sec-

tions at about 3 my. It seems probable that *Equus* evolved within the time span between the *Pliohippus* occurrence at 4 my and the first *Equus* occurrence at about 3 my. This is in conflict with recent K-Ar dates from Idaho (Armstrong *et al.*, 1975), which would place the well-known Hagerman *Equus* fauna at 5 my BP. It seems to us that the Hagerman age assignment is too old by at least 1 my.

The lowest occurrence of *Sylvilagus* is very similar in both sections, appearing in the lowermost Matuyama in the San Pedro Valley and in the uppermost Gauss at Anza Borrego. *Sylvilagus* may turn out to be a very important guide fossil for the late Pliocene/early Pleistocene. *Lepus*, the hare, occurs in both regions and is important in the definition of the Irvingtonian Land Mammal Age. In Arizona, its first occurrence was placed below the Olduvai event along with the last occurrence of *Stegomastodon*. Interestingly enough, the appearance of *Lepus* at Anza Borrego is also associated with the only occurrence of *Stegomastodon*. At Anza Borrego the first appearance of *Lepus* occurs above the first event within the Matuyama. The ambiguous age of this event has previously been discussed. If this event is the Olduvai, then this would imply that *Lepus* appears 300,000 yr later at Anza Borrego than in the San Pedro Valley. If, however, the event is the Réunion event, then *Lepus* would appear almost simultaneously in both regions.

Several other animals occur in the two sections, one being *Odocoileus*, the deer, which appears in sediments of the upper Gauss epoch at McRae Wash in the San Pedro Valley and in sediments of the lower Matuyama epoch at Anza Borrego. *Tanupolama* appears near the Kaena event in both localities. *Dipodomys* (kangaroo rat) appears in both sections within the lower Matuyama epoch.

It is clear that an overall similarity of the ranges of common genera exists between the two areas even though the Anza

Borrego section has a much more abundant fauna and higher rate of deposition than the San Pedro section. It is also clear that some important elements of the fauna which are present in the one area are missing from the other. For example, *Nannippus*, a three-toed horse, forms an important element of the San Pedro Valley fauna during the Gauss magnetic epoch, yet it is entirely missing at Anza Borrego. This difference may reflect different environments, or perhaps the geographic center of distribution of *Nannippus* was the high plains and the San Pedro Valley was on the margin of that range. The record of *Nannippus* is later (lower Matuyama epoch) in Texas. Similarly, sloths (e.g., *Megalonyx* and *Nothrotherium*) are present in the Anza Borrego region but absent from the San Pedro Valley during the Gauss epoch.

EURASIAN IMMIGRANTS

The ancestry of most genera of the Anza Borrego fauna is clearly from the New World; however, several genera (e.g., *Euceratherium* and *Odocoileus*) probably have an Old World origin. *Euceratherium*, the shrub ox, and *Odocoileus*, the deer, appear in the Anza Borrego section in the lower Matuyama epoch (1.7–2.0 my). It is reasonable to assume that the Bering land bridge was open to migration during the lower Matuyama magnetic epoch, allowing an exchange of some fauna at that time. *Mammuthus* (elephant), an Irvingtonian guide fossil, may or may not have crossed from Europe at this time. Unfortunately, this animal does not occur in the stratigraphically continuous part of the section under study. *Mammuthus* occurs 25 miles north of the Anza Borrego Desert, near Borrego, in a steeply dipping, truncated, and faulted section which cannot be precisely correlated with the continuous section studied here. Samples of sediment from above and below the occurrence of *Mammuthus* near Borrego are reversely magnetized. All that can be said is that

Mammuthus occurs in the Matuyama reversed magnetic epoch. *Microtus*, which occurs in the Anza Borrego section just above *Euceratherium*, has been ascribed a Eurasian origin by Repenning (1967). However, its earliest occurrence in Eurasia is within the Biharian at a level now known to be younger than 0.9 my BP (Berggren and Van Couvering, 1974). Thus, *Microtus* occurs in California approximately 1 my prior to its appearance in Europe. Interestingly enough, *Lepus*, which has been ascribed a Eurasian origin, occurs almost synchronously on both continents, 1.9 my in Europe (Flint, 1971; Zagwijn, 1974) and simultaneously in the San Pedro Valley (Johnson *et al.*, 1975). Therefore, this leaves the continent of origin for *Lepus* in doubt; it does suggest the Bering land bridge was open in the lower Matuyama magnetic epoch (about 2 my BP).

THE BLANCAN-IRVINGTONIAN BOUNDARY

Paleomagnetic and faunal data from Texas (Mt. Blanco), Kansas (Borchers), and California (Anza Borrego) indicate the transition between the Blancan and Irvingtonian faunas (as defined by the small mammals) occurs within the lower Matuyama magnetic epoch (Lindsay *et al.*, 1975). This transition is well marked in the San Pedro Valley (Johnson *et al.*, 1975) and the Anza Borrego Desert. In both stratigraphic sequences the change from one fauna to the other is transitional and deposition is continuous across this transition, with gradual replacement of Blancan genera by Irvingtonian genera. For example, the earliest record of genera more characteristic of Irvingtonian than Blancan in each sequence is *Tetrameryx* (pronghorn) in the Anza Borrego sequence and *Ondatra* (muskrat) in the San Pedro Valley sequence. Both of these genera occur with an assemblage of dominantly Blancan genera. *Tetrameryx* is also recorded from the Blancan Cita Canyon

fauna of Texas (Johnston and Savage, 1955) which has a normal magnetic polarity, and is regarded as being in the Gauss magnetic epoch (Lindsay *et al.*, 1975). Recently, Zakrzewski (1974) reviewed the fossil record of Ondatrini, and suggested the *Pliopotamys meadensis* of the Dixon and Deer Park faunas of Kansas may have given rise to *Ondatra idahoensis* of the Blancan Grand View fauna of Idaho. Hence, *Tetrameryx* and *Ondatra*, though characteristic of Irvingtonian faunas occur in several late Blancan faunas. Other mammals which are more characteristic of Blancan faunas persist into faunas which have an Irvingtonian aspect; this is particularly true of *Stegomastodon*, both at the San Pedro Valley and at Anza Borrego.

A problem in defining the Blancan-Irvingtonian boundary in both the Anza Borrego and in San Pedro Valley sequences is the absence of *Mammuthus*, the diagnostic Irvingtonian guide fossil (Savage, 1951). Faunal evidence in these two sequences indicates that a better characterization of Irvingtonian is needed. Lundelius *et al.* (in press) suggest the beginning of the Irvingtonian be recognized by the appearance of *Mammuthus* and *Lepus* plus the absence of diagnostic Blancan species, e.g., *Sigmodon medius*, *Nannippus phlegon*, *Equus (Dolichohippus) simplicidens*, and *Borophagus diversidens*.

The Blancan-Irvingtonian boundary is arbitrarily placed at the *Smilodon* LSD in the Anza Borrego sequence, and at the *Lepus* LSD in the San Pedro Valley sequence. The *Smilodon* LSD marks the appearance of *Smilodon* and *Dipodomys* in the Anza Borrego sequence; the *Lepus* LSD marks the appearance of *Lepus* and *Dipodomys* in the San Pedro Valley sequence. All of these genera are characteristic of Irvingtonian faunas. The ?*Euceratherium* LSD that overlies the *Smilodon* LSD in the Anza Borrego sequence marks the appearance of *Euceratherium* and *Lepus*, two other characteristic Irvingtonian genera. The sediments of the Palm Springs

Formation indicate a gradual replacement of the Blancan fauna by Irvingtonian forms through evolution and emigration over a period of time of several hundred thousand years. Therefore, the exact placement of the boundary between the Blancan and Irvingtonian Land Mammal Ages is more academic than real. The boundaries as given above are really a convenience to indicate the point at which the fauna becomes more characteristic of Irvingtonian than Blancan. This boundary occurs at about 1.9 my (below the Olduvai event) in the San Pedro Valley, and about 1.6 to 2.0 my (above the Olduvai or Réunion event) in the Anza Borrego section. On both instances, the change to a dominantly Irvingtonian fauna occurs close in time to the Pliocene-Pleistocene boundary, as defined in marine sediments within the Olduvai event (Berggren *et al.*, 1967).

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Cedros Island mammals

genus known from Neog. - San Juan @ Barnes

1 *Phocoenodelphis cedrosensis*

Barnes porpoise

tedfordi

Barnes

genus known from Neog. - San Juan & possibly Cedros
Albino Whistler

Barnes

genus known from Neog. - San Juan
Narrow (Parapontoporia pacifica)

Barnes (stenodelphinus dolphin)
dolphin-like

genus known from Neog. - San Juan
Cerro (Odonotoceti, incertae sedis type D)

Barnes (beluga)

genus known from Neog. - San Juan
Denebola brachycephala

sham whale

Physeterius incert. sedis

Barnes finny sham whale

genus known from Neog. - San Juan
Pachogia cedrosensis

Plesiocetus sp.

Balaenoptera or *Burtonoptera* sp.

rorqual

Reformis stipgini

Arctocephalus sp. nov.

Ducignathus sanctacruzensis

Kellogg

(walrus-like pinniped)

(*Reformis stipgini*?)

(Walrus)

Proceromys sp. new

Puffinus tedfordi

Puffinus sp.

Morus sp.

Megafalacrodon pygmaeus (Bridges)

Cerolonia minor

Eumycterus (?) sp.

Mauvella cedrosensis (Henslow)

from "Late Tertiary Cetaceans of the North-east Pacific Ocean - Barnes PhD Thesis 1972"

See Barnes Outline of Eastern No. Pacific Tertiary Cetacean assemblages
Systematic zoology

write ~~for~~
Clayton Ray
Dept Paleobiology
Nat Mus Nat Hist
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for Systematic Zoology vol. 25 no. 4 (Dec. 1974)
Symposium: Advances in Systematics of
Marine Mammals.

Clas Repennin Introduction

Whitman & Saunders - Oligo Cetacea

Laray Barnes East No. Pac, Pros. Cetacea

Savage - early Sirenia

Domning - Eolopius Model for Late Tertiary
Sirenia Evol. in No. Pacific

Tedford - Relation Pinnipeds to Other Carnivores

Repennin - Adaptive Eval. Sea Lions, Walrus

Clayton Ray - Geog. of Phocid Evol.

Grigorev - Parnotethyan Leals

Clayton Ray - ^{First} Marine Mammals of Oregon

Barnes Thesis - Some part of Almejas placed in
Delmontian to Repennian because of ^{more} primitive & 3 Parapontoporia
than San Diego & shares with Capistrano fm. - Albrecht.
Denebola occurs Almejas, Purisima & Drake's Bay.
San Mateo - older than San Diego because it has Pleistocene
San Diego has Cynus. Also San Mateo has Herpetocetus
a cetotheriid which suggests earlier Pleistocene age.

AAPG-SEPM SYMPOSIUM, Bakersfield, California, March 9-10, 1972

WEST COAST MIOCENE

Miocene Vertebrate Geochronology of the West Coast of North America

Donald E. Savage¹ and Lawrence G. Barnes²

Part 1: Nonmarine Vertebrates and Marine-Nonmarine Tie-Ins

Donald E. Savage

¹University of California, Berkeley and San Diego State College

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MIOCENE VERTEBRATE GEOCHRONOLOGY OF THE WEST COAST OF NORTH AMERICA

by Donald E. Savage¹ and Lawrence G. Barnes²

Part 1: Nonmarine Vertebrates and Marine-Nonmarine Tie-ins (Donald E. Savage)

With the conviction that an agreement regarding precise Miocene-Pliocene and Oligocene-Miocene boundaries within the stratal succession of the West Coast Region of North America is less important than the establishment of refined age and subage correlations within this region, we assign the following to the Miocene Epoch:

Epoch Subdivisions	Selected Geochronologic Units	Millions of Years B.P.*
Latest Miocene	Clarendonian mammal "age", Cerrotejonian and Montediablan mammal ages, San Pablo (Cierbo-Neroly) or Santa Margarita mega-invertebrate "ages", Mohnian and Delmontian foraminiferal ages	10
Late to Middle Miocene	Barstovian mammal "age", Briones and upper part of Temblor mega-invertebrate "age", later part of Saucesian plus Relizian and Luisian foraminiferal ages	12
Middle to Early Miocene	Hemingfordian mammal "age", earlier part of Temblor mega-invertebrate "age", middle part of Saucesian foraminiferal age	17
Earliest Miocene	Arikareean mammal "age" (early part may be Oligocene), Vaqueros-Temblor transition plus Vaqueros or Vaquerosian mega-invertebrate "ages", earliest part of Saucesian plus later part of Zemorrian foraminiferal ages	21
		26

*Year-dates are based primarily on the synthesis of Donald L. Turner (Geol. Soc. Amer. Spec. Paper 124, 1970).

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The Arikareean, Hemingfordian, Barstovian and Clarendonian "ages" are easily recognized from joint occurrence of fossils representing certain genera of insectivores, rodents, carnivores, mastodonts, horses, rhinos, oreodonts, camels, and other groups of mammals. We are now concerned chiefly with deciphering a more precise time-stratigraphic range for each of the species. We intend to establish a well disciplined (vertebrate) paleontologic stratigraphy, which can lead to zonation within the basins of nonmarine deposition.

Unfortunately, fossils of land vertebrates are rare in districts of littoral deposition, but the "classic" sections in the Tejon Hills, San Francisco East Bay, North Coalinga, Sharktooth Hill - Pyramid Hill, Caliente Range - Cuyama Valley, Tecuya - San Emigdio Range, South Mountain, and Santa Ana Mountains districts provide tie-ins between the generalized marine and nonmarine paleontologic stratigraphies and geochronologies of the Miocene.

Part 2: Marine Vertebrates (Lawrence G. Barnes)

Emphasis on faunal studies and intensified fossil collecting have shown that marine vertebrates in Miocene strata of the West Coast of North America are useful in paleontological correlation and in geochronology. Mammals, sharks, and bony fishes, in that order, are probably now the most useful groups for correlation and chronology; birds and turtles are less useful at present because they are less well studied. Associations of marine vertebrate fossils with terrestrial mammals and marine invertebrates at several localities have permitted correlations between land-mammal "ages" and marine ages.

There are three major chapters in the evolutionary history of marine vertebrates in the West Coast Miocene. These are termed early, middle and late and are roughly equivalent to "Vaqueros", "Temblor", and "Santa Margarita" ages respectively. Early Miocene faunas are characterized by archaic mammals (eurhinodelphid dolphins, squalodonts, early sea lions) and birds, and mixed types of sharks. Middle Miocene faunas are characterized by relict archaic mammals (eurhinodelphids, squalodonts, primitive sea lions), some highly specialized mammals (desmatophocine sea lions, desmostylians), and the earliest ancestors of living groups (modernized dolphins, cetotheres). Middle Miocene fishes are tropical, the birds are related to modern taxa, and the sharks are noticeably different from early Miocene species. Late Miocene faunas closely resemble middle Miocene faunas, with similar sharks and birds, but usually lack most of the archaic mammals and turtles and show increased numbers of modernized mammals (dolphins, baleen whales, modern sea lions). Transitions between these three major marine faunas of the Miocene are rarely found.

Part 1: Nonmarine Vertebrates and Marine-Nonmarine Tie-Ins

In the nonmarine succession of the West Coast the land-mammal "ages" here assigned to the Miocene Epoch are, from earliest to latest, ARIKAREEAN, HEMINGFORDIAN, BARSTOVIAN and CLARENDONIAN. For the original definitions and typifications of these ages, see Wood, et al. (1941). Each of these land-mammal "ages" is easily recognized on the basis of joint occurrence of fossils representing certain genera of hedgehogs, shrews, moles, squirrels, beavers, gophers, mice, dogs, mustelids, cats, mastodonts, horses, rhinoceroses, peccaries, oreodonts, camels, "deer", prongbucks, and other mammals. The total generic list for each "age" comprises 100 or more names. We are now concerned chiefly with deciphering more precise time-stratigraphic range for each of the species of these genera, and we hope to establish a well disciplined vertebrate paleontologic stratigraphy, which can lead to refined zonation within the basins of nonmarine deposition.

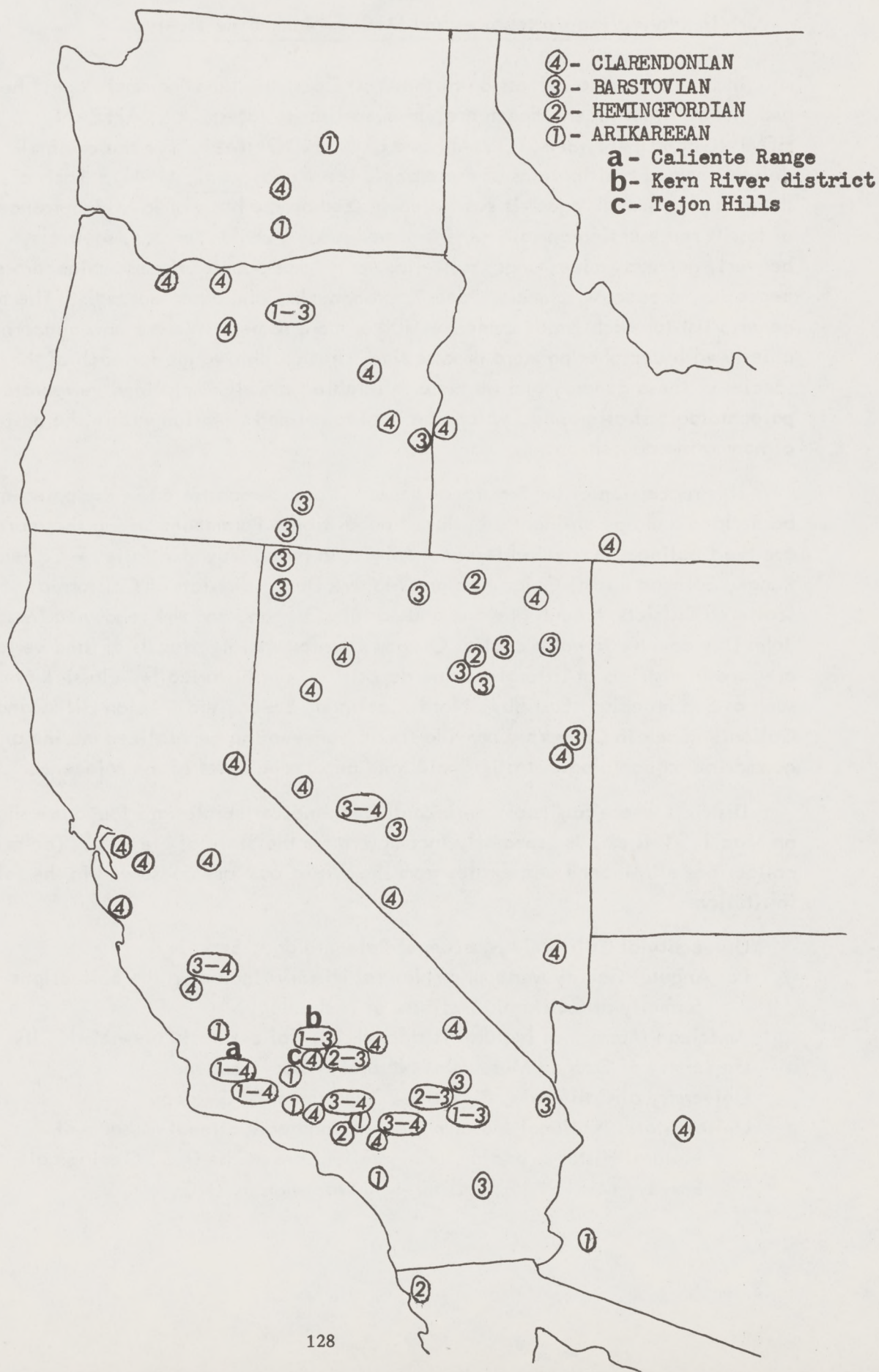
This succession of land-mammal "ages" is best demonstrated in the paleo-marine borderland and epicontinental basins of deposition. Paramount among these areas are the Coalinga, Bakersfield-Tehachapi-Tejon Hills, Cuyama Valley - Caliente Range, Soledad Basin, Cajon Pass and Mojave Desert districts of California, scattered districts through Nevada and eastern Oregon, and the renowned Mascall - John Day country in north central Oregon. Unfortunately, fossils of land vertebrates are rare in districts of littoral-marine deposition, but historically "classic" areas such as San Francisco East Bay, North Coalinga, Bakersfield - Tejon Hills, and the Caliente Range in California provide tie-in between the generalized marine and nonmarine paleontologic stratigraphies and geochronologies of the Miocene.

Districts where fossils of continental Miocene vertebrates are found are shown on Map 1. This map is especially incomplete for the State of Nevada. The principal collections of Miocene vertebrates from the West Coast are conserved in the following institutions:

- University of California Museum of Paleontology, Berkeley
- Los Angeles County Museum of Natural History (including the collections formerly at California Institute of Technology)
- American Museum of Natural History (Frick Collections), New York City
- University of Oregon Museum of Natural History, Eugene
- University of California, Riverside, Department of Geology
- United States National Museum (now designated National Museum of Natural History, and including collections at the U.S. Geological Survey, Menlo Park, California), Washington, D.C.

MAP 1

WEST COAST MIOCENE LAND-MAMMAL DISTRICTS



Raymond Alf Museum of Webb School, Claremont, California
 California Academy of Sciences, San Francisco
 Burke Museum of Natural History, University of Washington, Seattle
 Mackay School of Mines, University of Nevada, Reno
 University of California, Santa Barbara, Department of Geology and
 the Santa Barbara Museum of Natural History
 Central Washington State College, Department of Geology, Ellensburg

Complete locality information can be provided to qualified workers who write to the Curator of Fossil Mammals in the museum or department of each of these institutions.

THE LAND-MAMMAL "AGES" -- CHARACTERIZING AGGREGATES OF GENERA

In considering the characterizing aggregate for each land-mammal "age", given below, please keep in mind that none of these genera is confined necessarily to the "age" it helps to identify. Joint occurrence of genera is the significant criterion. Each "age" is characterized further by particular species within genera that may be long-ranging. Thus species phylogenies and "stage-of-evolution" continue to play a strong role in these age determinations.

ARIKAREEAN:

This "age" of the West Coast is characterized by the joint occurrence of fossils representing the following genera:

PROSCALOPS (moles)	MIOHIPPIUS (small browsing horses)
ARCHAEOLAGUS (rabbits)	DICERATHERIUM (cursorial rhinoceroses)
ENTOPTYCHUS (gophers)	DAEODON (giant omnivorous artiodactyls)
PALAEOCASTOR (beavers)	AGRIOCHOERUS (oreodons)
MESOCYON (dogs)	PROMERYCOCHOERUS (large oreodons)
HEPEROCYON (small dogs)	PARATYLOPUS (small camels)
NIMRAVUS (large cats)	NANOTRAGULUS (small "deerlets")

We are not certain about the phyletic origin of some of the genera of the Arikareean, especially certain insectivores, rodents and carnivores, but most were derived evidently from the preceding Oligocene fauna of North America. As would be expected, therefore, the Arikareean faunas show a strong transition between the so-called Paleogene and Neogene land mammals. Palaeocastor, Hesperocyon, Dinictis (large cats), Hoplophoneus (machairodont cats), Miohippus, Protapirus (tapirs), Hyracodon (small running rhinoceroses), Daeodon, many of the oreodons, Nanotragulus, and other genera are of Oligocene "stamp", but many of the rodent

genera, horses, and other taxa show accentuated phyletic trend toward late Cenozoic genera. Arikareean was the heyday of oreodont radiation; there is an almost bewildering array of "oreodons" at this time.

About six potassium-argon radiometric dates (three from the West Coast) have been obtained from volcanic rocks associated with Arikareean mammals. These dates range from 25.6 to 21.3 million years before present (Evernden, et al., 1964; Turner, 1970).

HEMINGFORDIAN:

This "age" of the West Coast is characterized by the joint occurrence of fossils representing:

HYPOLAGUS (rabbits)	PARAHIPPUS (browsing horses)
PSEUDOTHERIDOMYS (Old World rodents)	MERYCHIPPUS (three-toed horses)
PROHETEROMYS (Pocket mice)	APHELOPS (rhinoceroses)
MIOSPERMOPHILUS (ground squirrels)	TICHOLEPTUS (oreodons)
TOMARCTUS (dogs)	OXYDACTYLUS (slender camels)
*AMPHICYON (giant carnivores)	ALETOMERYX ("deer")
MOROPUS (chalicotheres)	

* - Also found in Eurasian Miocene or Oligocene

Hemingfordian faunas consist of a component of autochthonous taxa (evolved from Arikareean) --such as most of the rodents, some of the carnivores, the horses, the rhinos, and the peccaries, oreodons, camels, "deer" and prongbucks-- strongly supplemented by immigrants from Eurasia. Desmatolagus (rabbits), Pseudotheridomys (early Old World rodents), Plesiosminthus (jumping mice), Amphicyon, Hemicyon (early bears) and certain of the insectivores seem to have been new arrivals in North America at this time. The formerly poor representation of Hemingfordian on the West Coast is now being enriched by the collecting and describing of a new vertebrate assemblage from the Branch Canyon Formation in the Cuyama Valley area (Repenning and Vedder, 1961; Lindsay, 1972).

Two potassium-argon dates, both from the West Coast, are associated with Hemingfordian mammals. These are 17.4 and 17.1 million years before present (Evernden, et al., 1964; G. H. Curtis, personal communication).

BARSTOVIAN:

This North American land-mammal age is characterized on the West Coast by the joint occurrence of:

- | | |
|-------------------------------|---------------------------------------|
| *LANTHANOTHERIUM (hedgehogs) | *HEMICYON (early bears) |
| METERIX (hedgehogs) | *PSEUDAEELURUS (large cats) |
| LIMNOECUS (shrews) | *GOMPHOTHERIUM (long-jawed mastodons) |
| DOMNINOIDES (moles) | MERYCHIPPUS (three-toed horses) |
| HYPOLAGUS (rabbits) | ARCHAEOHIPPUS (small browsing horses) |
| LIODONTIA (sewellels) | APHELOPS (rhinoceroses) |
| MONOSAULAX (beavers) | BRACHYCRUS (oreodons) |
| PEROGNATHOIDES (pocket mice) | DROMOMERYX (permanent-horned "deer") |
| TOMARCTUS (dogs) | MERYCODUS (prongbucks) |
| *AMPHICYON (giant carnivores) | |

* - Also found in the Eurasian Miocene or Oligocene

There is a great percent of identity with the preceding Hemingfordian genera, suggesting evolution, in situ, at only species magnitude. New genera of the Barstovian are derivable from Hemingfordian stocks with the exception of the proboscideans Gomphotherium and Miomastodon, which taken a filtered dispersal at the end of Hemingfordian or beginning of Barstovian from the Eurasian continent. The most common Barstovian fossils are those of horses, camels, rhinoceroses, oreodons, prongbucks, rabbits and diversified rodents.

About ten potassium-argon dates have been obtained from volcanic rocks of the West Coast associated with Barstovian faunas. These dates range from 15.9 to 13.3 million years before present (Evernden, et al., 1964; G. H. Curtis, personal communication).

CLARENDONIAN:

The Clarendonian land-mammal "age" of the West Coast is characterized by the joint occurrence of fossils representing the following genera:

- | | |
|------------------------------|--|
| *LANTHANOTHERIUM (hedgehogs) | *GOMPHOTHERIUM (long-jawed mastodons) |
| DOMNINOIDES (moles) | PLATYBELODON (shovel-tusked mastodons) |
| SCAPANUS (moles) | *HIPPARION (world-circling horses) |
| HYPOLAGUS (rabbits) | MEGAHIPPIUS (large browsing horses) |
| EUCASTOR (beavers) | TELEOCERAS (amphibious rhinoceroses) |
| PEROMYSCUS (field mice) | PROSTHENNOPS (peccaries) |
| OSTEOBORUS (dogs) | USTATOCHOERUS (oreodons) |
| AELURODON (large dogs) | PROCAMELUS (camels) |
| NIMRAVIDES (giant cats) | MERYCODUS-COSORYX (prongbucks) |

* - Also found in the Eurasian Miocene

Apparently most of the Clarendonian mammals were descendants of stocks already in the West Coast area in Barstovian time; however, the possibility exists that certain hedgehogs and other insectivores, certain rodents (flying squirrels?), certain dogs ("Actiocyon"?), certain mustelids, a machairodont cat, and Platybelodon may have immigrated from Eurasia at about the beginning of the Clarendonian. The appearance of hipparions in the Old World at about the beginning of Clarendonian time in North America (ca. 12 million years b.p.) indicates that there was at least a limited dispersal of land mammals between the eastern and western hemispheres then, for Hipparion must be derived phyletically from Barstovian merychippuses. West Coast Clarendonian localities are usually supplied with a good representation of horses with high-crowned teeth (Hipparion, Neohipparion, Nannippus, Pliohippus), long-jawed and shovel-tusked mastodons, cricetid "field mice", Hypolagus, diversified camels (Procamelus, Pliauchenia, Protolabis, Aepycamelus, Megatylopus) and prongbucks. Oreodonts, so abundant and diverse in preceding Miocene ages, are drastically reduced in number of taxa (Ustatochoerus only) and in number of individuals. There is no post-Clarendonian record of this great North American group on the West Coast.

About ten potassium-argon dates have been obtained from volcanic rocks of the West Coast associated with Clarendonian mammals. These dates range from 11.7 to 9.9 million years before present (Evernden, et al., 1964).

MARINE - NONMARINE TIE-INS

One of the first detailed papers concerning marine-nonmarine tie-ins within the Cenozoic of the West Coast was by John C. Merriam (1915). His correlations, based on the well known succession of the North Coalinga district in California, set a standard for the West Coast Neogene which was followed for many years. Later, Stock (1924, 1939), Bode (1935), Eaton (1939), Stirton (1936, 1939), Drescher (1941), Durham, Jahns and Savage (1954), Savage (1955), Repenning and Vedder (1961), Evernden, et al. (1964), Turner (1970) and many others have been concerned with these phenomena. Some of the best established Miocene tie-ins are listed below in outline form:

ARIKAREEAN Tie-Ins (California):

1. Anchitherium (horses) and other land mammals of Arikareean aspect are associated with a large marine-vertebrate fauna in the Pyramid Hill sandstone, "Vaqueros", Kern County
2. Arikareean vertebrates in tongues of the lower part of the Caliente Formation, interfingering with tongues of the Soda Lake and Painted Rock Members of the Vaqueros Formation and with tongues in the lower part of the Saltos Shale Member of the Monterey, Caliente Range, Santa Barbara County (Repenning and Vedder, 1961)

3. Arikareean vertebrates in Pato Red Member of Vaqueros Formation intertonguing with marine Painted Rock Member of Vaqueros, carrying "Vaquerosian" molluscs = Turritella inezana "zone", Santa Barbara Canyon district, Cuyama Valley, Santa Barbara County
4. Miohippus and other possible Arikareean land mammals associated with marine vertebrates in the Sespe-Vaqueros "shoreline" beds at Bolero Lookout, Santa Ana Mountains, Orange County

HEMINGFORDIAN Tie-Ins:

1. cf. Aletomeryx and cf. Tomarctus in the Barker's Ranch marine vertebrate fauna, transition from Olcese Sand to lower Round Mountain Silt, Kern County (Addicott, 1970)
2. Merychippus carrizoensis, Amphicyon, Archaeohippus, Ticholeptus, etc. in tongue of Caliente Formation, which interfingers with tongues of the marine Branch Canyon Formation bearing "Temblor" molluscan fauna = Turritella ocoyana "zone" and with tongues of the Saltos Shale Member of the Monterey Formation, Caliente Range, Santa Barbara County (Repenning and Vedder, 1961)
3. Hemingfordian vertebrate local fauna (the Vedder locality) in nonmarine unit in Branch Canyon Formation, Cuyama Valley district, Santa Barbara County
4. cf. Oxydactylus (camels) and cf. Tomarctus associated with Desmostylus (marine pachyderms), cetaceans, pinnipeds, birds, sharks, rays, bony fish and molluscan fauna of "Middle Miocene" aspect = Turritella ocoyana "zone" in Rosarito Beach Formation, northwestern Baja California (Minch, Schulte and Hofman, 1970)

BARSTOVIAN Tie-Ins (California):

1. Merychippus "zone" fauna in top of marine Temblor Formation above "button bed" and "Temblor" molluscs, North Coalinga district, Fresno County
2. Several land mammals of Barstovian type associated with the tremendous marine-vertebrate fauna of the Sharktooth Hill bone bed, upper Round Mountain Silt, Kern County
3. Tomarctus, Archaeohippus mourningi, Merychippus sumani, and others of an assemblage indicating Barstovian in tongues of Caliente Formation which interfinger with upper "Temblor" and "Briones" part of marine Branch Canyon Formation, Caliente Range, Santa Barbara County (Repenning and Vedder, 1961)

CLARENDONIAN Tie-Ins (California):

1. Hipparion, Osteoborus and other genera indicating Clarendonian associated with marine molluscs and echinoids at several localities in San Pablo Formation, Contra Costa County
2. Hipparion and other land mammals with a great number of marine vertebrates beneath echinoid beds in the Santa Margarita Formation, Santa Cruz - Scotts Valley district, Santa Cruz County
3. Hipparion with or just below marine mammals, echinoids and molluscs in Santa Margarita Formation, Cammatta Ranch, San Luis Obispo County
4. Tejon Hills, Kern County:

North Tejon Hills vertebrate local fauna in Chanac Formation, late Clarendonian = Montediablan Stage of Savage (1955), overlying:

Comanche Point vertebrate local fauna in marine Santa Margarita Formation, early Clarendonian, which traces 3 miles southward into:

South Tejon Hills vertebrate local fauna in nonmarine Santa Margarita Formation, early Clarendonian = type of Cerrotejonian Stage of Savage (1955)

5. Early (and middle?) Clarendonian vertebrate fauna in Mint Canyon Formation below "San Pablo" or "Santa Margarita" invertebrates in marine Castaic Formation, Los Angeles County

Without doubt, the three most important Miocene districts for direct stratigraphic tie-in between sequences of fossiliferous marine and nonmarine rocks are:

- a. The Caliente Range, Santa Barbara County, where three stratigraphically successional land-mammal "ages" (Arikareean through Barstovian) are in rocks interdigitating with mollusc-rich marine beds --but with marine vertebrates scarce. The nonmarine and marine also intercalate here with basalts that have provided K/Ar radiometric dates. Here also, this interdigitation is overlain by continental strata (Upper Caliente, Quatal and Morales Formations) of Clarendonian and two later mammal "ages".
- b. The Kern River district, Kern County, where three stratigraphically successional marine vertebrate faunas (correlating with land-mammal "ages") are associated with marine invertebrate faunas of early through middle Miocene age --but with continental vertebrates scarce.

- c. The Tejon Hills, where Clarendonian vertebrates and "Santa Margarita" invertebrates are intimately associated stratigraphically --but with marine vertebrates scarce.

(Coincidentally, all three of these districts are within one hour's drive from the city of Bakersfield!)

We will continue to try to collect better paleontologic records of the Miocene marine-continental interdigitations. Chart 1 summarizes our conclusions regarding correlation between marine and nonmarine units of the Miocene of the West Coast.

Figure 2

EPOCH SUBDIVISIONS	SELECTED GEOCHRONOLOGIC UNITS	MILLIONS OF YEARS B.P.*
LATEST MIOCENE	CLARENDONIAN mammal "age", Cerrotejonian and Montediablan mammal ages, San Pablo (Cierbo-Neroly) or Santa Margarita mega-invertebrate "ages", Mohnian and Delmontian foraminiferal ages	10
LATE TO MIDDLE MIOCENE	BARSTOVIAN mammal "age", Briones and upper part of Temblor mega-invertebrate "ages", later part of Saucesian plus Relizian and Luisian foraminiferal ages	12
MIDDLE TO EARLY MIOCENE	HEMINGFORDIAN mammal "age", earlier part of Temblor mega-invertebrate "age", middle part of Saucesian foraminiferal age	17
EARLIEST MIOCENE	ARIKAREEAN mammal "age" (early part may be Oligocene), Vaqueros-Temblor transition plus Vaqueros or Vaquerosian mega-invertebrate "ages", earliest part of Saucesian plus later part of Zemorrian foraminiferal ages	21
		26

*Year-dates are based primarily on the synthesis of Donald L. Turner (Geol. Soc. Amer. Spec. Paper 124, 1970).

Part 2: Marine Vertebrates (Lawrence G. Barnes)

The scientific literature dealing with fossil vertebrates of California presents a wealth of papers dealing with isolated groups or taxa of Miocene marine vertebrates, but there may be found few faunal summaries or phylogenetic studies. A paper by Mitchell (1966) was one of the first attempts to present a picture of changing types of marine mammals through the Cenozoic Era in the northeast Pacific Ocean. The present paper is a survey of the prominent groups of Miocene marine vertebrates, particularly mammals, of California and their arrangement into successive faunal units. This is only a preliminary step in the process of erecting a marine vertebrate chronology for the Pacific Coast of North America.

The major Miocene marine faunal aggregates in California appear to fall into three general time brackets, somewhat separated by gaps in time, each represented at one or two well studied localities and several less well known localities. The three time brackets may be referred to as earliest, late-middle, and latest Miocene in age, and are shown on the correlation chart (Fig. 3). Many of the known marine vertebrate faunas occur in sediments deposited in near shore environments. Mega-invertebrates and terrestrial mammals are commonly associated, and in most cases there are associated foraminifera, allowing relatively accurate correlations of marine vertebrates with the chronologies established in the other paleontologic subdisciplines.

EARLIEST MIOCENE:

The oldest well known Miocene marine vertebrate assemblages in California are of earliest Miocene age from Kern County at Pyramid Hill and near Willow Spring, and occur in the Jewett Sand. The two localities have somewhat different lithologies and suggest different sedimentary environments, but produce similar marine vertebrate faunas. At Pyramid Hill, in the Pyramid Hill Sand Member of the Jewett Sand, associated with marine vertebrates are mollusks and land mammals that indicate Vaqueros and Arikareean ages. A typical assemblage of marine vertebrates in earliest Miocene time is:

- Isurus sp. (primitive species of bonito shark)
- Carchardon sp. (small species of great white shark)
- Pristiophorus (saw shark)
- Plotopterum (extinct cormorant-like bird)
- Squalodon (shark toothed whale)
- Allodelphis (long nosed dolphin-like animals)
- Macrodelphinus (long nosed dolphin-like animals)
- Argyrosetus (long nosed dolphin-like animals)

Figure 3. Suggested correlations of important Miocene marine vertebrate faunas in California.

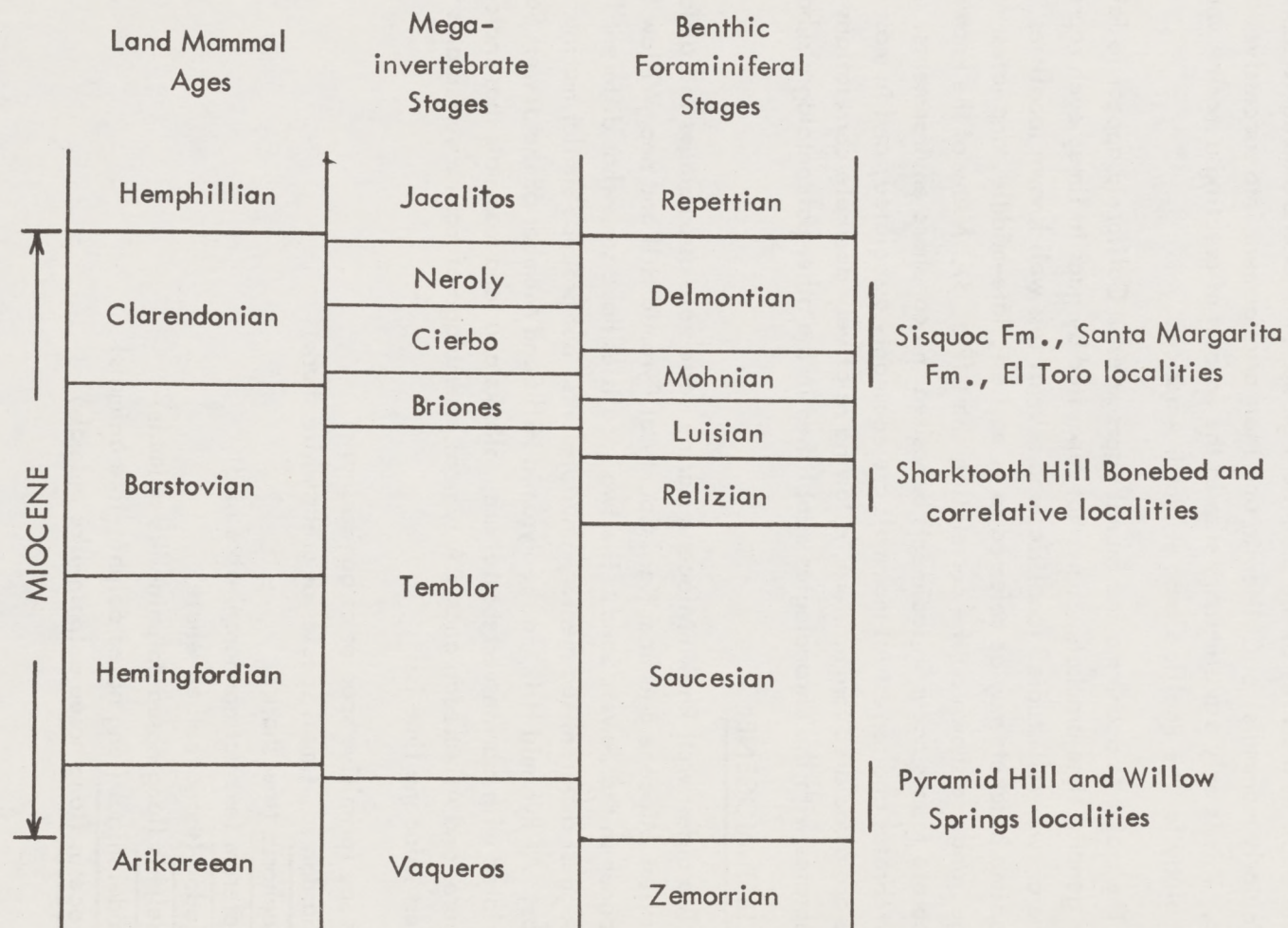
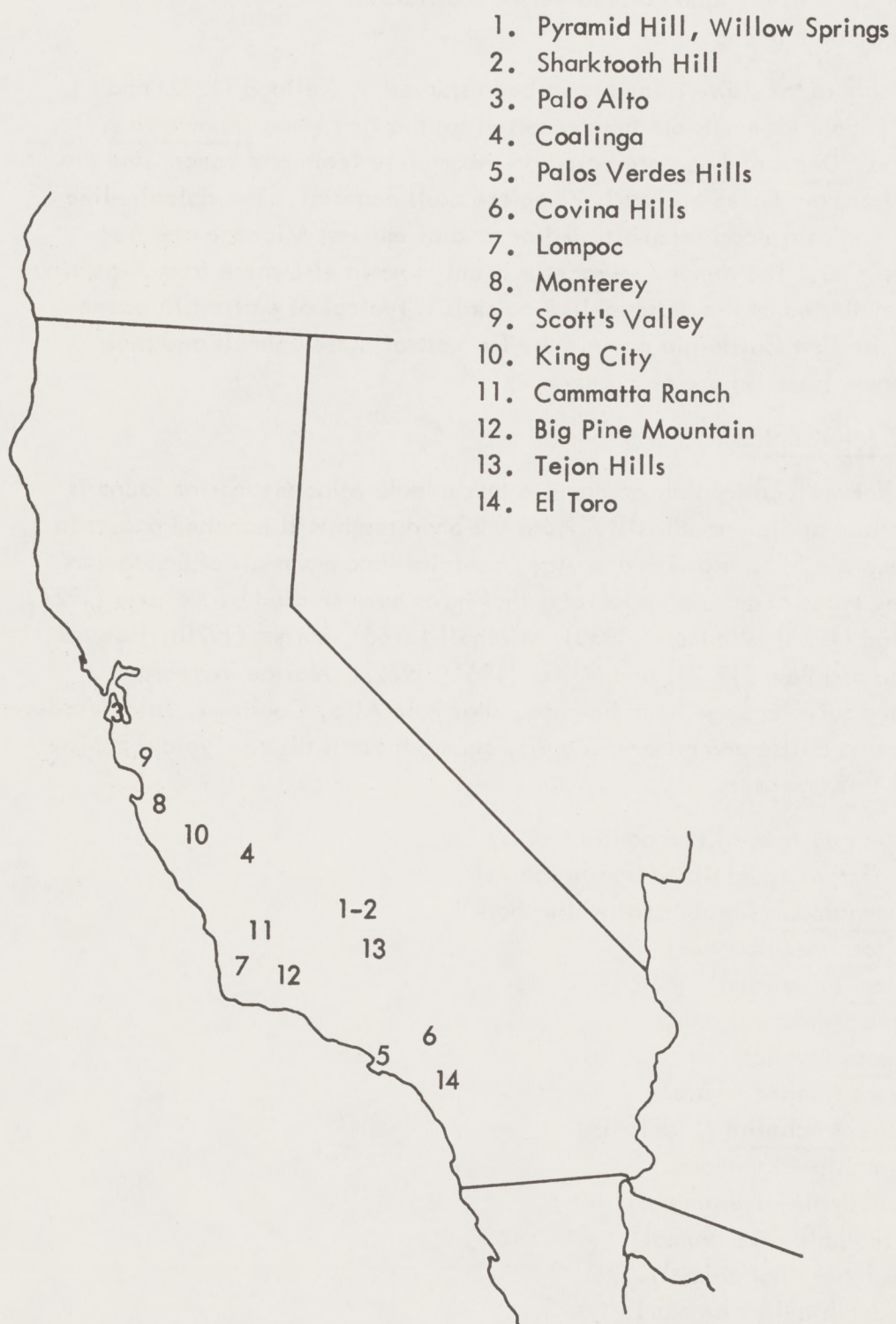


Figure 4. Geographic locations of important Miocene marine vertebrate localities in California.



Miodelphis (long nosed dolphin-like animals)
Eurhinodelphis (long nosed dolphin-like animals)
 ?Desmatophoca (ancestral desmatophocine sea lion)
Otariidae (very primitive, land carnivore-like sea lions)
Desmostylus (marine sub-ungulate)

The mammals in the Jewett Sand have been studied by Kellogg (1932) and Wilson (1935). Four mammals are here reported for the first time; Desmostylus, Squalodon, and ?Desmatophoca are based on incomplete teeth and bones, and the primitive sea lions are based on nearly complete skull material. The dolphin-like animals have long rostra and resemble similar taxa of earliest Miocene age from Italy and Argentina. The genus Argyrosetus is only known elsewhere from Argentina. The grade of evolution of the dolphin-like animals is typical of earliest Miocene time. This is the first California occurrence for most of these animals and their prior evolutionary histories are obscure.

LATE MIDDLE MIOCENE:

The best known locality that produces a late middle Miocene marine fauna is east of Bakersfield at Sharktooth Hill. Here the Sharktooth Hill Bonebed occurs in the Round Mountain Silt, is of Temblor Age, contains land mammals of Barstovian Age, and many types of marine vertebrates that have been studied by Kellogg (1927, 1931), Compton (1936), Wetmore (1930), Mitchell (1966), Barnes (1970), Howard (1966), Jordan and Beal (1913), and Miller (1961, 1962). Marine vertebrate assemblages of equivalent age have been found at Palo Alto, Coalinga, Palos Verdes Hills, and Covina Hills, and generic identity among these is high. Typical marine vertebrates of this age are:

Isurus planus (large, specialized bonito sharks)
Isurus hastalis (large, specialized bonito sharks)
Carcharodon megalodon (large great white shark)
Diomedea californica (albatross)
Diomedea milleri (albatross)
Puffinus inceptor (shearwater)
Morus vagabundus (gannet)
Squalodon (shark toothed whale)
Liolithax hemisyntrachelid(?) (dolphin)
Oedolithax (dolphin-like animal)
Lamprolithax (dolphin-like animal)
Nannolithax (dolphin-like animal)
Platylithax (dolphin-like animal)
Grypolithax (dolphin-like animal)

Loxolithax (primitive porpoise relative)
Aulophyseter (sperm whale)
Idiophyseter (sperm whale)
Tiphyocetus (cetothere)
Peripolocetus (cetothere)
?Parietobalaena (cetothere)
Neotherium (small, primitive sea lions)
Allodesmus (advanced desmatophocine sea lions)
Paleoparadoxia (marine sub-ungulate)
Desmostylus (marine sub-ungulate)

Among these late middle Miocene vertebrates some are descendants of early Miocene species, some are new groups making their first appearance in California, and others are the earliest representatives of groups that predominate in later time. Among the first group are Squalodon, Neotherium (the small sea lion), Allodesmus (which is very common and typical), and Desmostylus. The groups that make their first appearance at this time may be immigrants or may have ancestors that are as yet undetected in the earlier Miocene rocks of California. These include most of the birds, the numerous cetotheres, the sperm whales, and dolphin-like animals. The hemisyntrachelids, porpoises, and cetotheres are groups which are typical in later geologic time. The grade of evolution among the cetaceans suggest correlation in age with the Calvert Formation of Maryland, but faunal identity on the generic level is not high.

LATEST MIOCENE:

The latest Miocene vertebrates are known from exposures of the Santa Margarita Formation of the California Coast Ranges at Scotts Valley, King City, Cammatta Ranch, Sespe Valley, and in the Tejon Hills. Faunas of roughly equivalent age are known from the Sisquoc Formation at Lompoc, the Monterey Formation at Monterey, and the basal part of the Capistrano Formation at El Toro. The rock units involved have a Clarendonian land mammal age and Mohnian to Delmontian foraminiferal age (Savage, 1955; Hill, Carlson, and Dibblee, 1958; Hoots, Bear and Kleinpell, 1954; White, 1956; Clark, 1965). Typical marine vertebrates of this time period are:

Isurus planus (large, advanced bonito sharks)
Isurus hastalis (large, advanced bonito sharks)
Carcharodon megalodon (large great white shark)
Puffinus diatomicus (shearwater)
Praemancalla lagunensis (primitive flightless auk)
Hemisyntrachelidae (generalized proto-dolphin)
Lophocetus (generalized proto-dolphin)

Delphinapterinae (primitive belugas or white whales)

Phocoenidae (generalized harbor porpoises)

Cetotheriidae (primitive baleen whales)

Megaptera miocenica (humpback whale)

Balaenoptera ryani (primitive rorqual whale)

Allodesmus (advanced desmatophocine sea lions)

Imagotaria (sea lion-like walrus)

Pithanotaria (primitive fur seal)

Metaxytherium (sea cow)

Desmostylus (marine sub-ungulate)

Paleoparadoxia (marine sub-ungulate)

The latest Miocene vertebrate assemblages are a mixture of middle Miocene types and of new types of animals that are ancestral to elements in the modern fauna. The sharks, birds, cetotheriids, Allodesmus, and Desmostylus are among the former group. The Praemancalla, belugas, porpoises, hemisyntrachelids, humpback whales, rorquals, fur seals, and sea cows are mostly primitive members of phyletic lineages that became predominant in Pliocene and Quaternary times. Most of these probably originated from ancestors living on the coast of California, but some (Metaxytherium, Lophocetus, Megaptera) may be immigrants from the Atlantic Ocean where the genera are known earlier in time.

The time gap between the late middle Miocene and latest Miocene faunas presented here is probably less than that between the earliest Miocene and late middle Miocene faunas (Fig. 3), and it is during the bulk of the Saucian Stage or the Hemingfordian Age that many gaps occur in California marine mammal evolution. Fossil localities representing this period of time (Hemingfordian Age) would be welcome additions to the record. Two such localities, the Barker's Ranch horizon in Kern County, and the Rosarito Beach Formation, have yielded, respectively, a primitive hemisyntrachelid dolphin, and a eurhinodelphid, ?Neotherium, and Desmostylus, but more specimens are needed before a meaningful faunal assemblage is recognized.

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DEPARTMENT OF PALEONTOLOGY

BERKELEY, CALIFORNIA 94720

May 20, 1974

P. Rich

TO: B. Patterson, J. Gregory, P. Brodkorb, M. Woodburne, E. C. Olson, W. Clemens, P. Robinson and J. Van Couvering, R. Sloan, M. McKenna, R. Emry, R. Tedford, *✓* L. Barnes and E. Lundelius

Dear Colleagues,

With respect to our proposed memoir or special paper in the G.S.A. publications on "Vertebrate Paleontology as a Discipline in Geochronology, Examples and Problems":

Three splendid contributions have been received (Olson, Lund, Emry). Others are said to be forthcoming by the time you receive this message (Woodburne, Sloan, Barnes, Behrensmeyer, Lundelius).

This is a final earnest plea for you who have not done so to get your manuscripts to me for collation before you depart for summer field exercises.

Try!

Sincerely,

Donald E. Savage

DES:bgb

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OK 067A+B - Tefunguit

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APRIL make his list his list.

Comparative Miocene Study

March, 1980

copy Amt 2)
1980

p. 13 none has
been studied
in detail

VCLAP
abbrev

COMMENTS from HH p. 1

page 004 Abstract. Shouldn't the localities be listed here in the order in which they appear in the text OR geographically from north to south? As given, the Monterey Formation of Orange County is sandwiched between the Modelo and Puente of LA. County, with the Monterey of L.A. Co. coming in again at end.

Check mammal and fish records for Tepusquet. Unless there are some, it is wrong to include Tepusquet among the localities containing "at least three of these taxa."

006 Alphabetize the list of published records

008 Alphabetize the acknowledgments

009 Alphabetize the list of abbreviations. include United States National Museum

030 Wouldn't it be better to leave this as Santa Margarita Formation rather than to have to go through the whole manuscript and change the designation?

032 "where the two skulls were found." Delete the the of is there a previous reference to two skulls?

033 Do we or don't we capitalize Late Miocene, Middle Miocene, etc.? It looks strange to speak of early late Miocene without capitalizing Late.

035- 038 Why do the fishes and birds come between two very similar discussions of horses on p 35-36 and 38?

045 Begin by identifying the group the bone belongs to

042-46 (and also table of contents)

check spelling of Cammatti	Commatti	Comatta	Comatti
p 42	p 006	p 46	contents

Towsley Formation. If there are no fish or birds from this formation, the fact should be mentioned. Perhaps it is on p 052, but I can't read it.

060 Where is Modelo Canyon? It is compared here with "upper member of the Modelo from the north side of the Santa Monica Mts." as though it is rather distant from there.

064 First paragraph on Monterey Formation. List localities in order in which they will be presented.

066 Clarify "these" First reference is to the higher part of the Monterey Formation in Laguna Niguel. What does the second "these" refer to?

2/12/80

Where are my keys of my revisions?

OVER

APRIL
Chuck Miala
media 1945-again
after conclusions?

015-018
SCS (unc. bld)

037 Scotts Valley
his reference

061-62
Birds, Modelo

065A-065B
Birds Tepusquet

*if Miguel included
there are more than 4 sites
Apr 1980*

*APRIL check Mon
in cabinet for
human like
Palo
Solo
?
fun
Evan*

page 067 Does "Laguna Hills" refer only to the lower levels or does it include the more southerly upper levels? You refer to "four sites." Should they be listed by LACM numbers, or isn't this always necessary?

068 Why the euphemism of "housing development" for Leisure World? Leisure World would place the site more definitely. Or were some of the fossils found in "New World" farther west on El Toro Road?

*070-072 →
Budo Dec 1945
now nbs 2 pages
070-071 on one page*

078 LACM 1101 is LACM locality 1101?

079 Add "The holotype" from the Sisquoc Formation...."

080 Reference to Pithanodelphus
Add "as recorded herein from the Modelo Formation
LACM locality 1230."

*085-086
Budo Valmont*

090 Why discuss water temperature of the time before ~~th~~ and after the Late Miocene without mentioning what it was during the Late Miocene?

092 is a repeat of 091

*094 add
reunions
Mioceles, Palaeo
+ Cretaceous
2 sites?*

Literature cited. Don't forget all the Gilbert, Jordan, Jordan and Gilbert, David, and Zawacki references given in the discussion of the Sisquoc.

Since there are two Orrs in the literature cited, they should be distinguished by their initials in the text. The one on p 013 is Phil Orr, so should read (Orr, P., 1954) The Robert Orr is in my copy on the birds, and I have noted it.

What about commas between author and reference throughout? They are omitted in LACM publications. This should be checked for the publication we are using before final typing.

page 035 clarify whose locality. Several references on this page to M1104 and V4004. And I see that there is also a reference to a USNM specimen, so be sure to include USNM in the list of abbreviations, on page 009

089-093 Page 093 seems to follow directly the thought conveyed on page 089. The two pages in between throw the reader off from understanding what "this assemblage" (on page 093) refers to.

095

Delete all of this page. Material is covered elsewhere now

*in chub
Dorchester
in last at
and chub
for monkey 1945,
Santo Miguel
NEW April
X in Miguel
X in other*

Bird specimens occur in the Modelo Formation at four San Fernando Valley localities, and at one site farther east--in El Sereno near the city limits of Alhambra.

Most of the specimens from the San Fernando Valley occur as incomplete skeletal impressions of associated elements. Unlike the Lompoc imprints from the Sisquoc Formation however, portions of fragmented bones are present.

Three species of Sulidae are recognized. One specimen (LACM 2704) from LACM locality 1267 in Sherman Oaks, was assigned (Howard, 1962) to Sula willetti. It consists of leg bones whose proportionate lengths are nearly identical to those of the holotype from the Sisquoc Formation. A second specimen (LACM no. 2674) from LACM locality 1229 in Studio City, was described as Sula pohli Howard, 1958. It is similar in body size to Sula willetti but differs in wing proportions. The third specimen, consisting of leg bones and incomplete humerus and ulna (LACM 5001 from LACM locality 1752 near Encino) is unrecorded and requires further study. It represents a gannet-like species of large size, possibly undescribed.

Also recorded from LACM locality 1267 in Sherman Oaks is an incomplete skeleton (LACM 2705) assigned (Howard, 1962) to the Sisquoc Formation species, Puffinus diatomicus. Also at this locality toothed jaw fragments and an atlas referred (Howard and White, Howard, 1957 1962) to Osteodontornis orri were recovered. The latter species was described from the Monterey Formation in Tepusquet Canyon, Santa Barbara County, and is found as well, at Monterey Formation sites in Orange County.

A fourth San Fernando Valley site, near Calabasas, yielded the holotype partial skeleton of the cormorant, Phalacrocorax femoralis Miller, 1929 (UCMP) which is unknown elsewhere.

A single humerus (LACM 2533) was found in the Modelo Formation in Elsereno (LACM locality) and was assigned (Howard, 1958) to Palaeosula stocktoni (Miller, 1935), the type of which is from the Valmonte diatomite in Lomita. Originally described as Sula stocktoni Miller, 1935, the assignment to a new genus Palaeosula Howard, 1959 was based on the El Sereno bone, which reveals ^{qualitative} characters only hinted at in the associated wing bones of the type.

$$\begin{array}{r} 23 \overline{) 7.0} \\ \underline{69} \\ 10 \\ \underline{21} \end{array}$$

$$\begin{array}{r} 14 \overline{) 3.0} \\ \underline{28} \\ 20 \end{array}$$

+ibia 8.9?
Gr dist 6.8-8.4 million
9.0-11.1 degrees
? 8.4

Spur & Grant 1932

Geol & Paleont a portion of LA Calif
Calif. Div Mines & Geol 30:371-415

Repetto = early Pleistocene (foram det)

in NW Puente Hills dips conformable
above Repetto contains mollusks
of late Pleist.

An equid mollusk fauna occurs
in south-dip strata down to the
from 6th & 7th & 8th & Hill (see
Spur & Grant 1932. Fauna
here too assigned to Pico
by Wissler 1943)

(Calif. Div Mines Bull 118
pp 209-234)